January 1957

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NUCLEONICS

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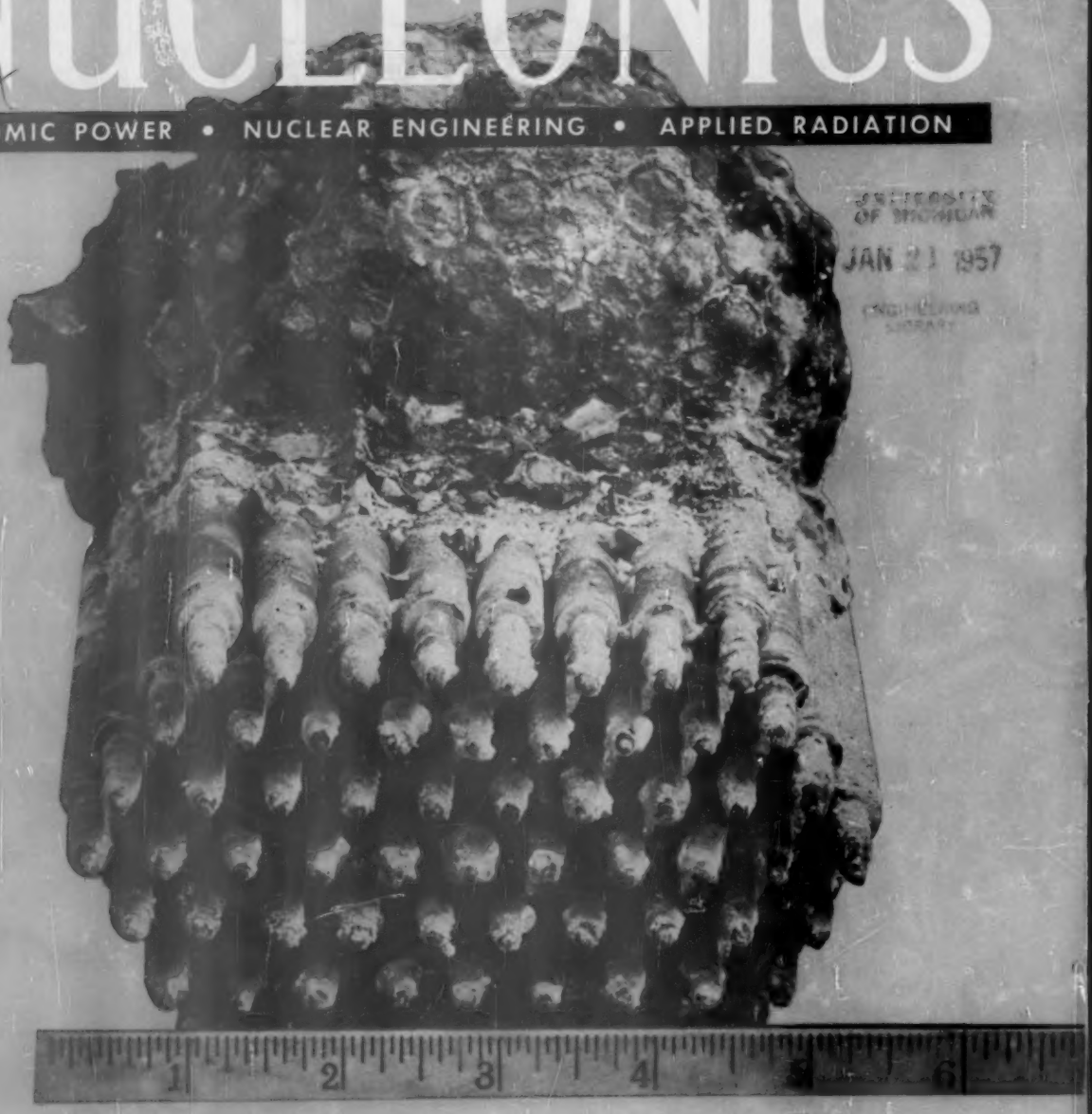

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What the World Thinks of U. S. Nuclear Program

page R6

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ABOUT NUCLEONICS

The end product in the publishing business is the printed page, the printed word. As with many businesses, there is not necessarily any relationship between the scope of the manufacturing effort and the size of the final object.

Such is the case with the two-page special report on p. R6. There are only about 2,000 words in this article. But they were distilled from a mass of data, which, if published in toto, would have filled most of this issue of NUCLEONICS.

However, even this doesn't convey the spirit and magnitude of the effort that lay behind the compilation of the data on which the report is based. The article, which is quite impersonal, except for the quotations at the end of it, is based on very personal information. In fact, our correspondents in the 11 countries covered by the survey had all shades of personal experiences in gathering the information. Some found people quite eager to cooperate. Others met resistance.

An example of the latter is seen in this statement by one of our men: "Many were hostile to the idea of being questioned and may have shown this hostility in their replies. But more important, I sensed a definite unwillingness on the part of most of those questioned to admit that perhaps the U. S. was doing something worthwhile."

At the other extreme was this view from one country: "Most people interviewed were quite pleased with filling out questionnaires on atoms-for-peace, but they didn't know much about it."

In an effort to get a good cross section of reactions, we had our correspondents canvas opinions of the mythical "man in the street." These interviews included a number of taxicab drivers, an artist, a concierge, one reporter's barber, and the like. Probably the man who was most in the street was the one interviewed in Spain—a traffic policeman. According to our man, the policeman "turned out to be quite an interesting guy. He is young, has learned English quite well after one year of study on his own and worked harder and more conscientiously at answering than some of the others."

All in all, getting responses to the

ABOUT NUCLEONICS
CONTINUED

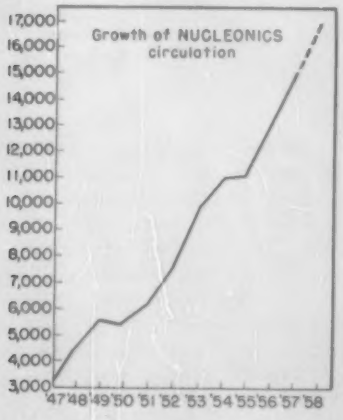
survey did not prove difficult, although it took all of the six weeks allotted for the purpose.

The idea for the study came out of a luncheon discussion last year not very long after the Gore bill was defeated. With the Gore bill said to be motivated by the feeling that the U. S. was falling behind the U. K. and the U. S. S. R. in nuclear power, the question in our minds was, "Did people of other nations think we were falling behind?" As it turned out, the results of the survey can probably be used by either side.

•

This issue of NUCLEONICS is Volume 15, Number 1. September of this year will see us celebrating our tenth anniversary. (The reason for the seeming discrepancy in volume numbers results from our publishing two volumes a year while we were in our pocket-size format through 1951.) We feel so old in this young nuclear business that we figure we'll be excused if we rear back and review some of the history of our growth.

Almost immediately after the atomic bomb was dropped over Japan in 1946, the McGraw-Hill Publishing Company jumped into the nuclear publishing business by issuing several mimeographed periodicals. Then, in September, 1947, the company moved in with both feet by issuing NUCLEONICS in letterpress form in a small format. The venture was more or less of an experiment and no advertising was taken. To get the magazine off on the right foot, a high-level editorial board of leading scientists from this country and others was named.



Our first real milestone came in 1952 when McGraw-Hill decided that atomic energy was here to stay and expanded the physical size of the magazine along with its coverage. The next milestone, which saw a big spurt in industrial interest in the field, came with the passage of the Atomic Energy Act of 1954.

This brief history shows up very clearly in the circulation growth chart shown on this page. We started with a circulation of about 3,000. This gradually rose to 7,500 in 1952. Then, in one year, it shot up to 10,000 and leveled off in 1954 at about 11,000. Came the new law and its effect moved us up to our present 15,000 number. We now plan to raise this to 17,000 by the end of this year.

An explanation of this last statement is probably warranted. Contrary to what most people think, neither we nor any other McGraw-Hill publication seeks merely to add as many new subscribers as can be obtained. We're looking for quality rather than quantity. Our efforts are directed at building a hard core of subscribers whose interests lie directly in our respective fields. Because commercial publications depend upon advertising revenue for income, a balance is sought between number of subscribers, cost of serving those subscribers, and rates charged advertisers. The number 17,000 represents the next "balance" point for us.

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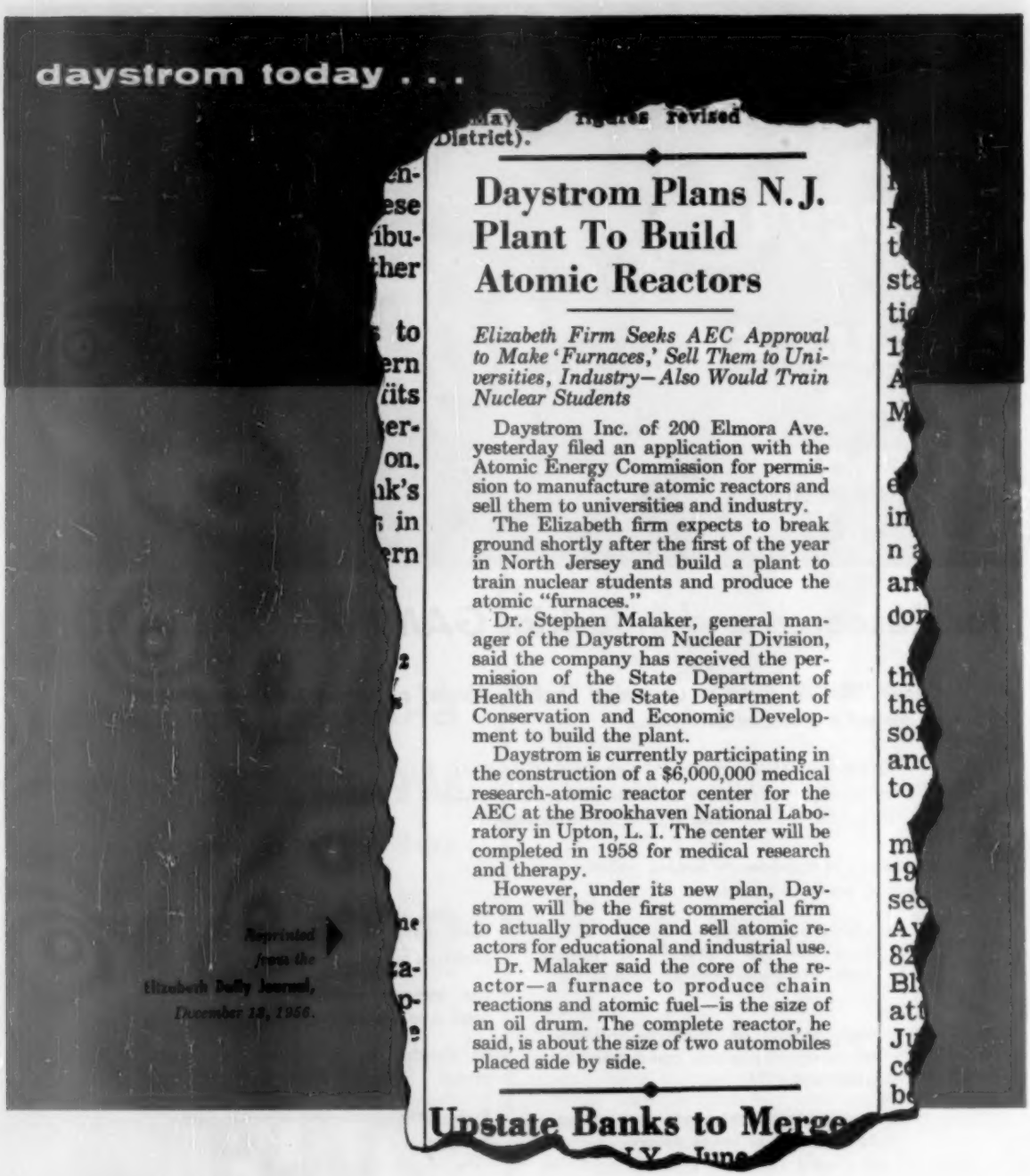

(District).

Daystrom Plans N. J. Plant To Build Atomic Reactors

Elizabeth Firm Seeks AEC Approval to Make 'Furnaces,' Sell Them to Universities, Industry—Also Would Train Nuclear Students

Daystrom Inc. of 200 Elmora Ave. yesterday filed an application with the Atomic Energy Commission for permission to manufacture atomic reactors and sell them to universities and industry.

The Elizabeth firm expects to break ground shortly after the first of the year in North Jersey and build a plant to train nuclear students and produce the atomic "furnaces."

Dr. Stephen Malaker, general manager of the Daystrom Nuclear Division, said the company has received the permission of the State Department of Health and the State Department of Conservation and Economic Development to build the plant.

Daystrom is currently participating in the construction of a $6,000,000 medical research-atomic reactor center for the AEC at the Brookhaven National Laboratory in Upton, L. I. The center will be completed in 1958 for medical research and therapy.

However, under its new plan, Daystrom will be the first commercial firm to actually produce and sell atomic reactors for educational and industrial use.

Dr. Malaker said the core of the reactor—a furnace to produce chain reactions and atomic fuel—is the size of an oil drum. The complete reactor, he said, is about the size of two automobiles placed side by side.

Reprinted from the Elizabeth Daily Journal, December 18, 1956.

Upstate Banks to Merge

...LY — June ...

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30 Watt Transistor Magnetic Amplifier
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*Immediate delivery

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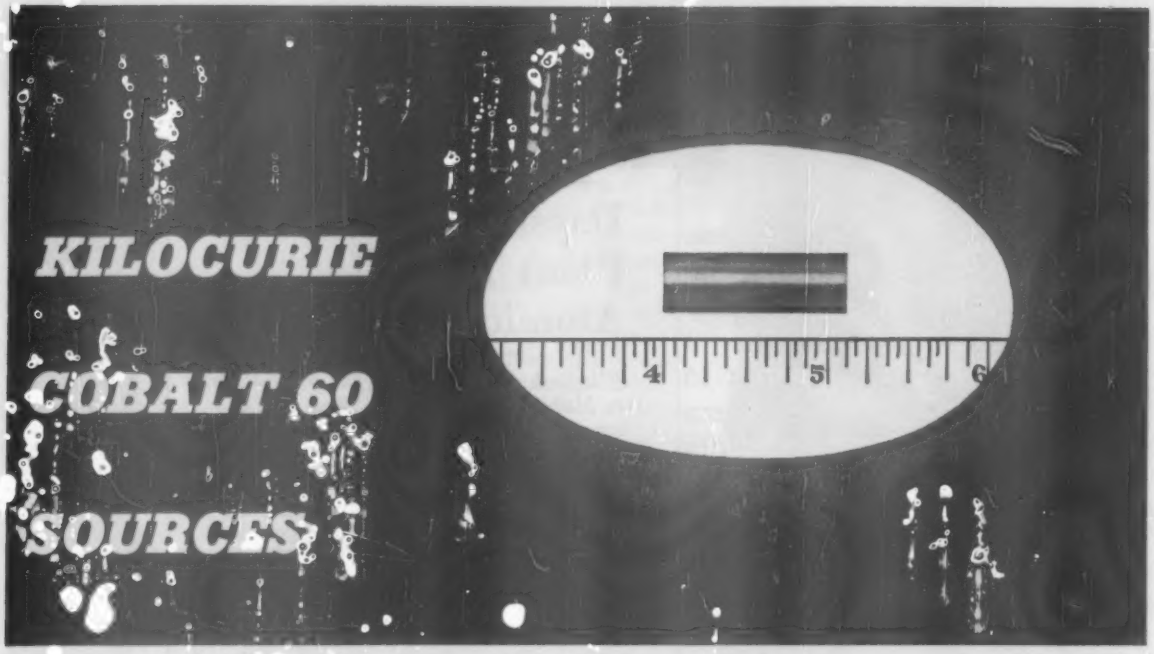

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Using the "building block" technique, Cobalt 60 SLUGS can be assembled in cylindrical, rectangular or linear form. The individual SLUGS are Cobalt rods 1" long and ¼" diameter clad in 1/16" aluminum.

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- **as durable as a simple piece of metal.**
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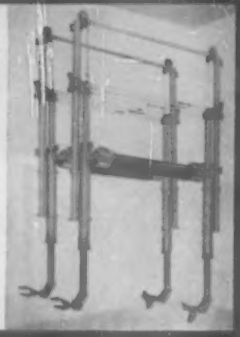
CRL Model 4

for over-wall installation

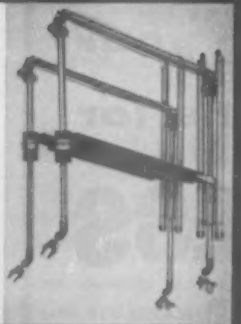
A general purpose manipulator for installation over a barrier wall or through a ceiling opening of a protective enclosure.



CRL Model 7

for restricted space installation

A space conserving, light weight manipulator for use in hoods or over thin walls where minimum clearances and easy portability are important factors.



CRL Model 8

for thru-wall installation

A general purpose manipulator for installations requiring intermediate to high level shielding, the Model 8 features

- *Accurate "sense of touch"* Low friction forces . . . low backlash . . . low inertia
- *Greater versatility* A variety of tools, tongs and locking motions available
- *Easier sight control* Operator need not step back to bring materials to barrier window
- *Ease of relocation* Can be withdrawn and moved by one man in five minutes with a light crane

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1. *Cranes and hoists* For moving heavy loads in hot cell areas by remote control. They are specially designed by CRL for use with CRL manipulators.

2. *Flexible booting* Protects slave end from dust and contamination. Restricted gas-flow seal possible. Won't interfere with manipulator's natural movements.

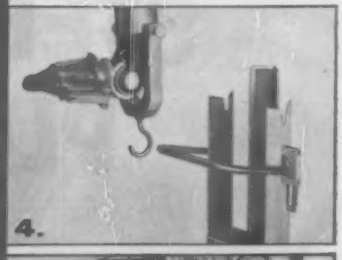
3. *Special-purpose tongs* For repetitive or highly specialized operations. Wide selection of types to meet all requirements.

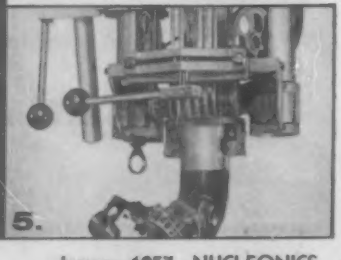
accessories

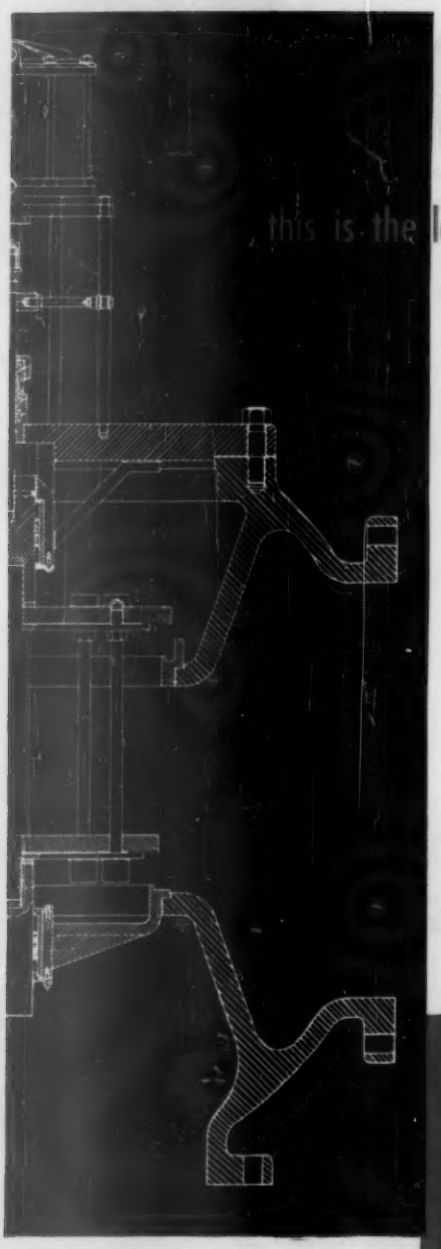
for master-slave manipulators

4. *Load hook* Available for CRL Model 8; may be remotely attached or removed. Permits a vertical lift of 60 lbs.

5. *Motion locks* Permit objects to be rigidly positioned in space. *Locking grip* standard on all models. Locks for all other motions available as accessories.







this is the largest double-seated control valve ever made

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Write for Bulletin CV-53.

ABOVE: Partial cross-section of K&M 36-inch valve showing general construction.

AT RIGHT: Actual size of a 36 inch valve can be visualized from this illustration of a workman inside the valve body performing finishing operations.

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At the country's largest design-engineering center for nuclear power reactors, Bettis Plant in Pittsburgh, operated for the Atomic Energy Commission by Westinghouse, the application of nuclear power has progressed rapidly. However, the nuclear power plants already in operation today represent only the beginning of a new technological era. *Major advances in many areas are necessary.*

These include: the development of new uranium alloys for use in reactor cores; greater understanding of reactor physics, of heat transfer, and of the effects of radiation on materials; development of new and improved components such as valves, pumps, heat exchangers, and instruments to meet the new severe requirements.

To do this, Bettis Plant needs farsighted men. Regardless of your interest, you can choose a place in the varied operations at Bettis Plant.

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All at once you can *record* and *read the record* of the Visicorder. Using a completely new direct-recording principle, the Visicorder puts six channels on a direct-reading record at sensitivities comparable to photographic oscillographs, and at frequencies from DC to 2000 cps!

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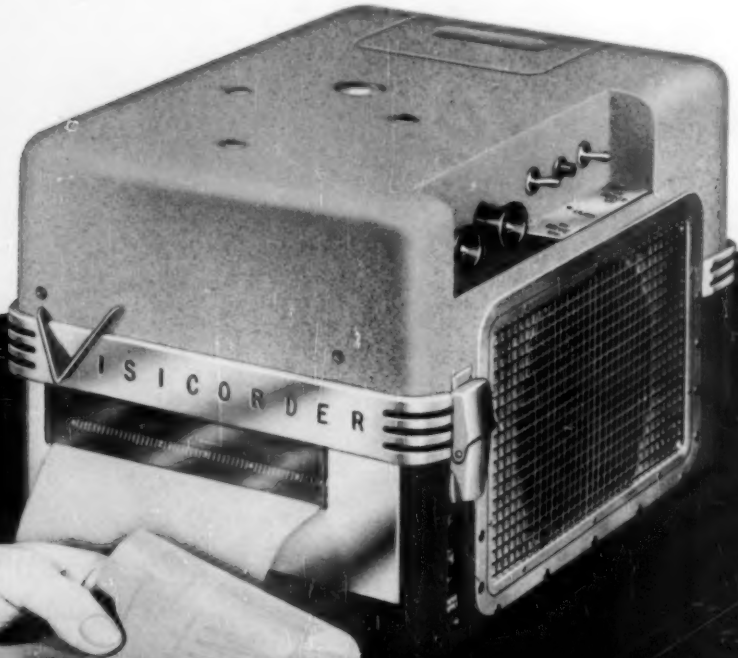

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THE **NEW** *VISICORDER,* perfected after years of research by the Heiland Division of Honeywell, combines the high frequency and high sensitivity characteristics of photographic oscillographs with the convenience of a direct-recording instrument.

By means of a completely new type of recording paper, light source, and optical system, the Visicorder makes use of mirror-type galvanometers to record phenomena from DC through 2000 cps *without* peaked amplifiers or other external compensation.

The record requires no liquids, vapors, powder magazines, or other processing materials. Development is accomplished by external light only as the record emerges from the oscillograph.

The Visicorder records are stable and require no further processing under normal conditions. They may be subjected to room light for extended periods without fading, and are permanent indefinitely when protected from light. Should it be necessary to subject the records to direct sunlight, they may be chemically "fixed" (in room light) using conventional photographic practices.

Visicorder records are reproducible by several methods using commercially available equipment.

Since the Visicorder operates on light-beam galvanometers, traces may deflect the full 6" width of the chart, peak to peak, and their deflection is not limited by adjacent channels.

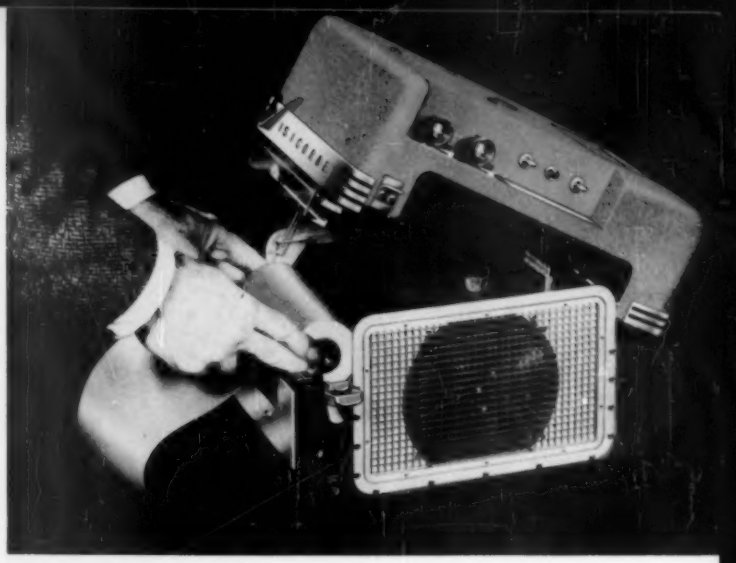
The remarkable exclusive features of the Visicorder make it the ideal recording oscillograph for applications where readable, permanent analog records are required and for additional uses where the measured phenomena need to be monitored or where immediate recorded results are desirable.

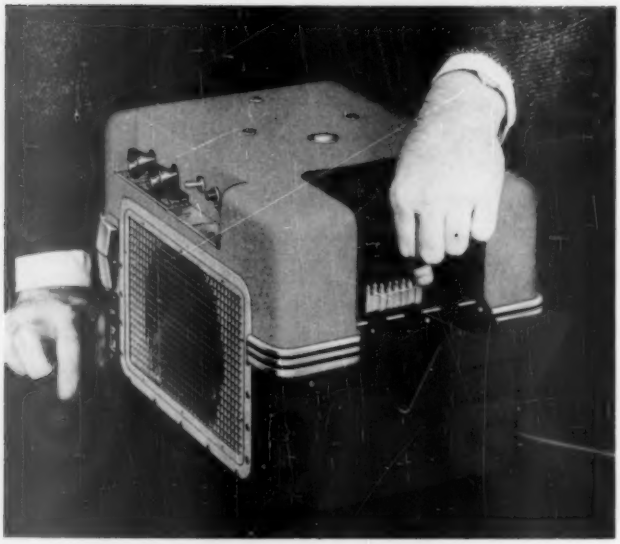
GENERAL FEATURES

FREQUENCIES	From DC to 2000 cps without peaked amplifiers or other compensation of any kind.
SENSITIVITIES	Comparable to photographic-type oscillographs.
RECORDING METHODS	Records directly on paper which requires no powder magazines, liquids, vapors, or other processing. Records are immediately visible and usable. Daylight loading. Accommodates recording paper 100 feet in length. Indicator shows unused recording paper available.
NO. OF CHANNELS	6 channels on 6" wide paper plus provisions for two timing traces.
DEFLECTION	Full 6" peak to peak. Traces may overlap; not limited by adjacent channels.
RECORD SPEEDS	0.2, 1, 5, and 25 inches per second, minute, or hour.
GALVANOMETERS	D'Arsonval-movement mirror galvanometers with choice of natural frequencies to suit individual requirements.
AMPLIFICATION	None required for most applications.
POWER	115 volt 60 cycle AC operation. 4 amperes.
DIMENSIONS	10" height; 15" depth; 10" width.
WEIGHT	37 pounds, complete and ready to operate.
PRICE	$2,500.00, less galvanometers. Galvanometers $150.00 each.

Deliveries starting January, 1957

❶ *THE VISICORDER* is the first and only photographic-type oscillograph that can be loaded with recording paper in daylight. The paper speeds can be selected while the instrument is in operation. The light spots from the galvanometers are *visible from the exterior* at their point of contact with the paper; thus phenomena can be monitored simultaneously with their recording.





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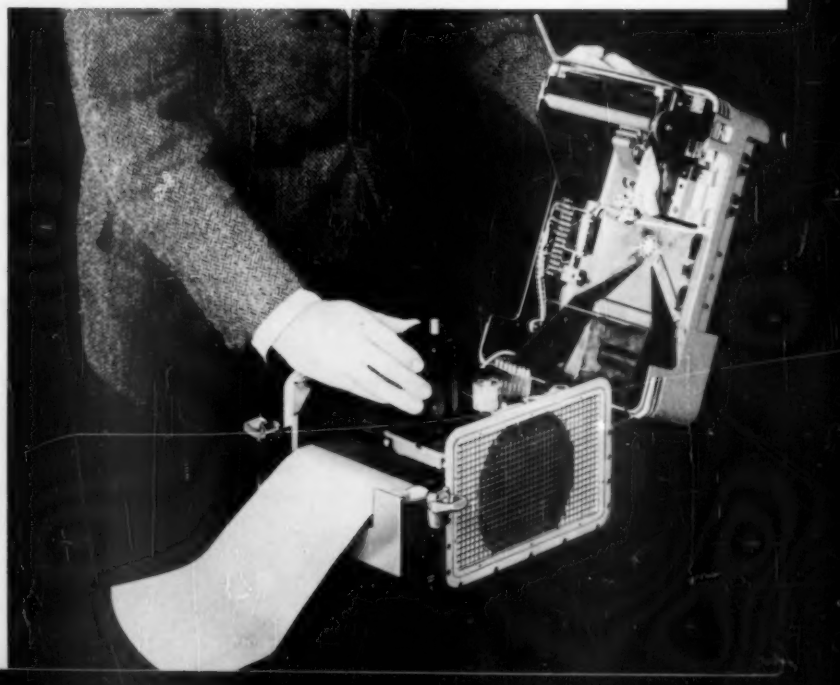
❸ *SERVICE* on the Visicorder is extremely easy, since the instrument opens completely as shown. All components—galvanometers, recording lamp, transmission—are completely accessible.



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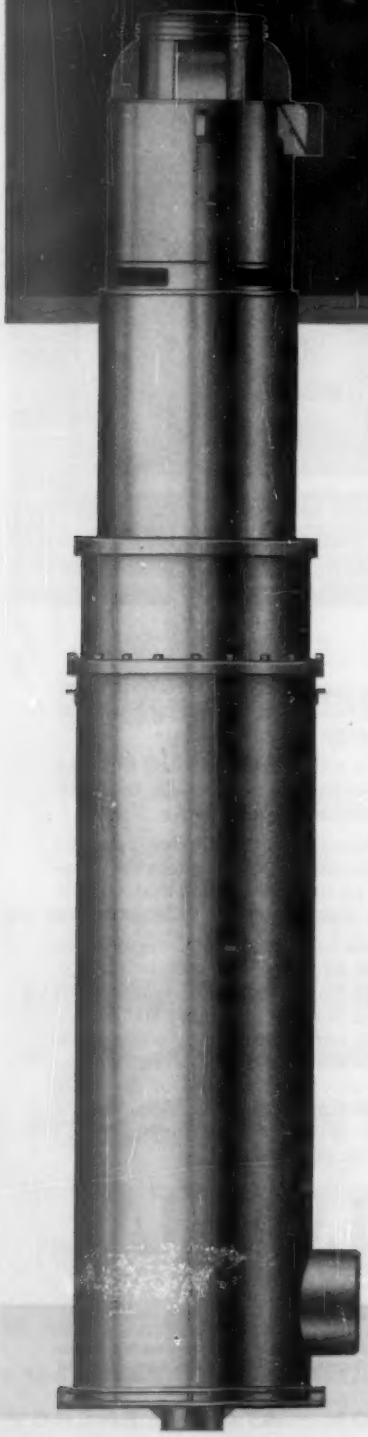
Another Byron Jackson FIRST in NUCLEAR PUMPS...



BJ Liquid Sodium Pump

WORLD'S LARGEST LIQUID SODIUM PUMP FEATURES MANY DESIGN "FIRSTS"

This new Byron Jackson pump will be used as a primary cooling pump for one of the nation's first full-scale commercial power plants using nuclear fuel.

The pump is approximately 32 feet high with a 6 foot diameter. Rated at 1000 hp, it will pump liquid sodium at a temperature of 1000° F. and deliver 11,800 gpm against a total dynamic head of 310 feet.

Of special interest are Byron Jackson's engineering accomplishments in designing the pump and installation for "packaged" removal. Basically the pump is divided into two sections—(a) suction tank incorporating suction and discharge nozzles which will be permanently welded into the system, and (b) the complete motor and pump assembly which can be pulled as a unit for routine maintenance and inspection with maximum ease, speed and safety. The "packaged" design even provides for shielding (normally separate from the pump assembly) to be integrated within the pump motor support assembly.

This record-making liquid sodium pump with its special design features marks another step in Byron Jackson's continuing leadership in the liquid metal pumping field.

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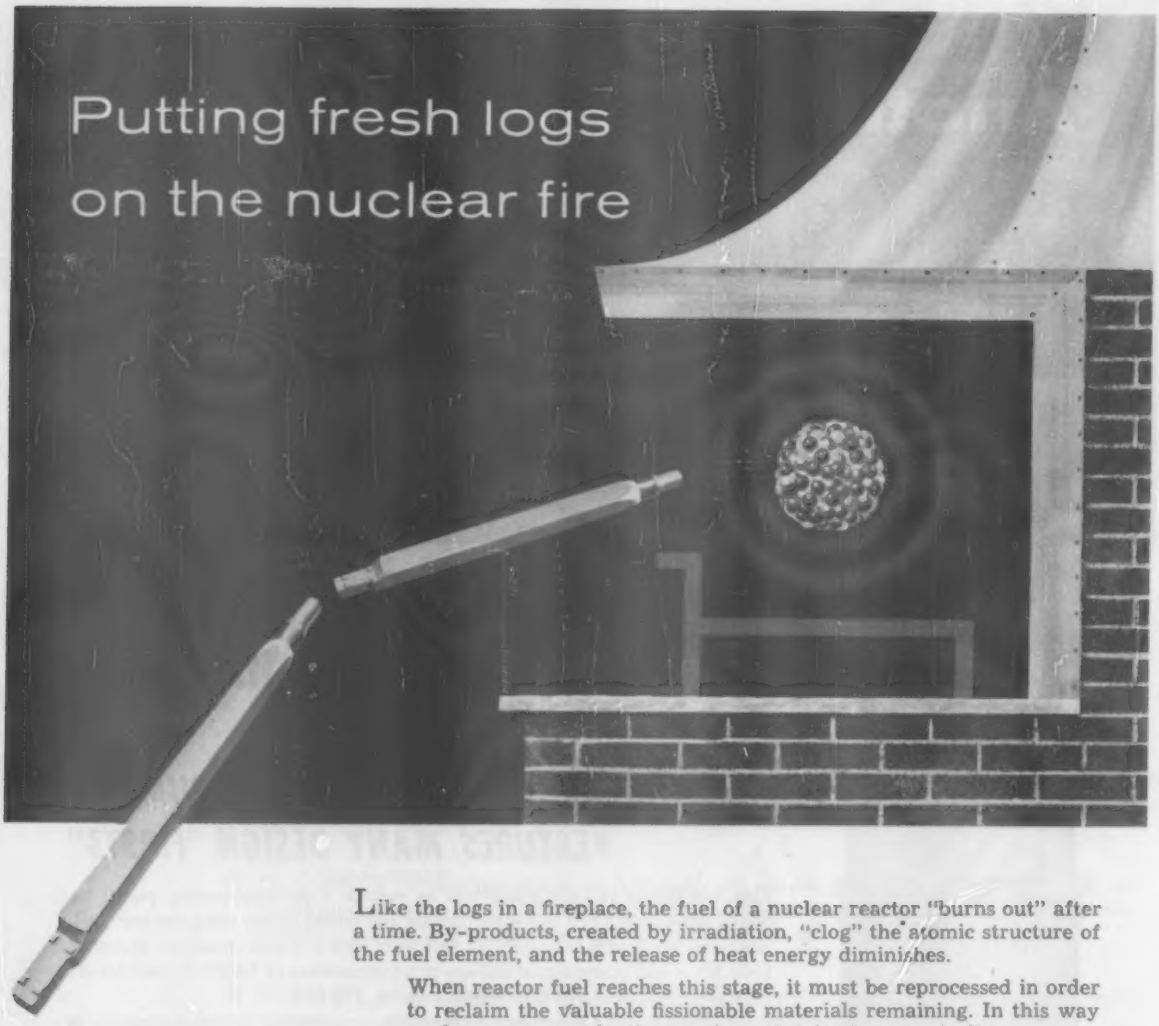
Putting fresh logs on the nuclear fire



Like the logs in a fireplace, the fuel of a nuclear reactor "burns out" after a time. By-products, created by irradiation, "clog" the atomic structure of the fuel element, and the release of heat energy diminishes.

When reactor fuel reaches this stage, it must be reprocessed in order to reclaim the valuable fissionable materials remaining. In this way nuclear power production can be maintained economically.

The reprocessing of spent fuel elements is a task that requires expert knowledge, specialized equipment, and considerable practical experience. It is, in general, an outside service that will be required by reactor operators.

With more than eight years of successful experience in solving advanced technical problems in atomic energy, Sylvania has long been a leading processor of reactor fuel elements and assemblies, as well as a pioneer in the development of fuel elements and reprocessing techniques. Whether your reactor plans are immediate or for the future... for power or research... international or domestic ...our scientific and engineering staff will gladly discuss your problems with you. For your files, write for Sylvania's just-published booklet on Nuclear Fuels.

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Vol. 15, No. 1 - January, 1957

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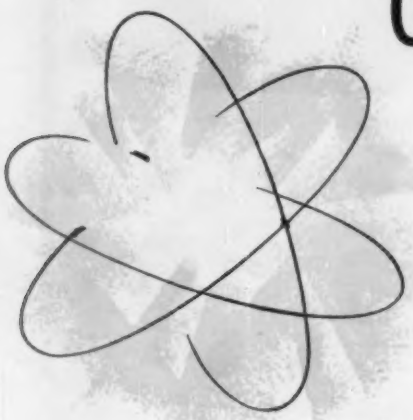

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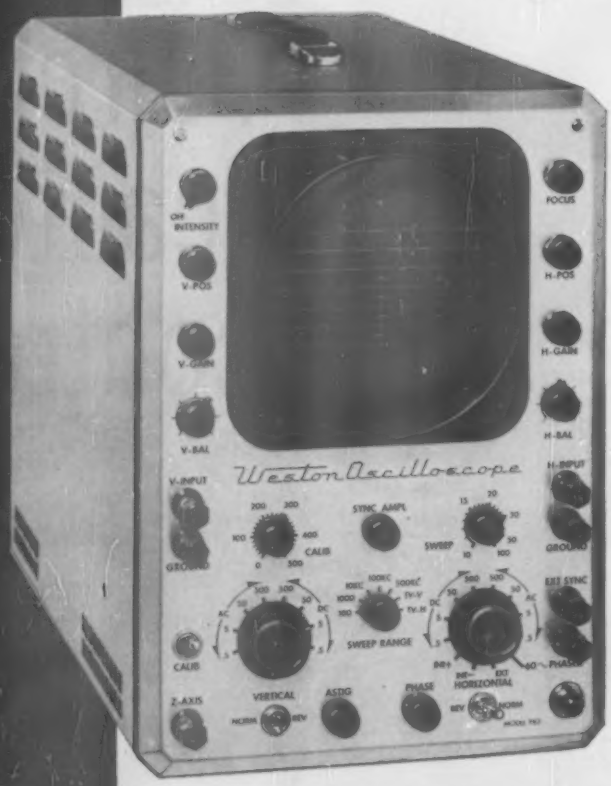

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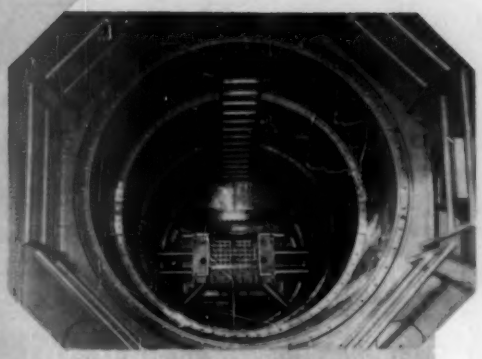

Omega West, newest of the research reactors at Omega site in Los Alamos, is one of several reactors in operation or under development at the Laboratory. The OWR is designed for high flux at low cost, flexible operation, and has extremely versatile port facilities. This installation is an important addition to the impressive array of research facilities available to Los Alamos scientists.

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NDA

BR II—An Engineering Test Reactor

for

C.E.A.N. at Mol, Belgium

Belgian Reactor II, an engineering test reactor of advanced concept, is scheduled for completion at Mol, Belgium, in 1959. Built and operated by Belgians in Belgium, BR II is the outgrowth of fifteen years of experimental and testing reactor development in Europe and America.

NDA has been joined by senior C.E.A.N. personnel in the detailed design, engineering, and development of BR II. NDA will continue to assist C.E.A.N. through construction and test operation in order to add U.S. experience to the abilities of C.E.A.N. and Belgian industry.

Centre d'Etudes pour les Applications de l'energie Nucleaire

BR II

NDA NUCLEAR DEVELOPMENT CORPORATION OF AMERICA
White Plains, N. Y.

ROUNDUP of Key Developments in Atomic Energy

Westinghouse sells 134-Mw plant to Italian utility

The world's first export order for a large-scale nuclear power plant went to the U. S.—and Westinghouse. Edisonvolta S.p.A. of Milan, operating subsidiary of Società Edison, Italy's largest electric system, placed the order, for "essentially a duplicate" of the pressurized water reactor Westinghouse is building for Yankee Atomic Electric at Rowe, Mass. This 134-Mw plant will cost $34.5-million (AEC is contributing $5-million worth of research and development), and Charles Weaver, head of atomic activities for Westinghouse, said the Italian reactor's cost would be similar, although "obviously costs are different in Italy and Massachusetts." He said he hoped Westinghouse would break even on the deal ("I object to the statement that nuclear power must necessarily be a losing operation"). The firm has a contract limited to equipment, and contingent on conclusion of a power bilateral with Italy. Gibbs and Hill are advisers on the project. Use of an oil-fired superheater is under consideration.

Weaver and Giorgio Valerio, managing director of Edisonvolta, both said they hoped the station could go on the line "soon after the Yankee plant is in operation." That is scheduled to happen in 1962. Signor Valerio had announced intention of buying a U. S. power reactor in the 100-Mw range when he was here in September 1955. The 11.5-Mw power reactor that Westinghouse sold to Belgium a year ago—first power reactor sold abroad, but which has since run into delays over site difficulties—"is being held in abeyance" but "can be expected to proceed on a normal basis very shortly," Weaver said.

AEC rejects last three second-round proposals

Plans of Holyoke, Mass., for a 15-Mw nitrogen-cooled nuclear gas-cycle power plant have been turned down by AEC on the ground technical feasibility has not yet been demonstrated and further r & d work is needed. Orlando, Fla.'s plan for a 25–40-Mw LMFR was turned down on the same grounds, while the 2-Mw pressurized water reactor proposal of Florida U., last of the seven bids in the second round of AEC's power reactor demonstration program, was rejected as too small to qualify.

IAEA names aide

Paul Rodolphe Jollies of Switzerland has been named executive secretary of the preparatory commission for the International Atomic Energy Agency.

Middle South Contemplates Two-Stage Nuclear Project

Middle South Utilities, Inc., has asked four manufacturers for designs of a reactor for its system.

Atomics International, General Electric, Westinghouse, and General Nuclear Engineering Corp. (Walter Zinn's new firm) have been asked "to identify a conceptual design of a power reactor which, if built in prototype size of around 20 Mw electrical capacity, would contribute importantly to the advancement of reactor technology." In addition, the design should hold promise of being economical if scaled up to large size in the next reactor generation. Construction cost estimates for both the small pilot and the large plant are to be provided. Middle South expects the proposals by the end of January.

Strauss Proposes An Acceleration Plan

Responding to a rising tide of demands that the nation's civilian nuclear power program be accelerated, Lewis L. Strauss broached an eight-point program in some respects going beyond the provisions of last summer's controversial Gore bill.

The chairman of the Atomic Energy Commission emphasized that he was only speaking for himself on behalf of a program he intended to lay before the Commission, but that it had not yet acted upon. He spoke in Washington at the first winter meeting of the American Nuclear Society, attended by 1,067 nuclear scientists and engineers.

The eight points of the plan:

1. A third round of the Power Demonstration Program, but open without deadline to all proposals for plants scheduled to be completed by a June 30, 1962 target date. Each proposal would be considered individually and acted on as received.

2. Governing criterion in this third round would be "whether a project promised to make a significant contribution towards achieving cheap, abundant and safe nuclear power," with no limitation placed on size or type of plants proposed, and no discrimination between proposals of privately- or publicly-owned firms or groups.

3. Priority, however, would be given three particular reactor types, in this order: a Savannah River type (natural U fuel, D_2O moderator) reactor of at least 100-Mw capacity; a fluid-fuel reactor also of at least 100 Mw based on aqueous solutions or slurries containing U or Th; and thirdly, three small-scale reactors of varying designs.

4. First crack at building the plants in point 3 would go to industry; but if "acceptable proposals" were not made in "a reasonable period of time," AEC would "take prompt and positive steps to build those reactors on its own initiative," for completion by June 30, 1962.

5. A greater share of the cost of research and development—as distinct from construction costs—would be borne by the government. This proviso would apply retroactively to the first and second rounds of the Power Demonstration program, as well as to the third; and "would in-

volve not alone the design of reactors themselves, but the improvement of materials, cheaper and longer-lived fuel elements, reactor physics, heat transfer methods, fluid mechanics, chemical processing, waste disposal, reactor safeguards."

6. Phased waiver or reduction of the use charges made by AEC on lease of nuclear fuel would provide further assistance to industry; also, no charge would be made for the use of D_2O as moderator in a natural uranium reactor for the first five years of operation.

7. Chemical processing charges that AEC would ask for treating fuel elements in U. S.-owned facilities should be set "at an early date."

8. Reactors for non-power uses would be included in AEC's "new and more elastic partnership with industry." This would cover reactors for space heating, process heat, food sterilization, etc.

These proposals, Strauss said, "would in large measure apply to our aid to friendly nations as well."

He said the plants he was specifically recommending "would be of entirely new type and design, as compared with the reactors currently being built commercially or planned." However the Pennsylvania Advanced Reactor, a 150-Mw homogeneous type using uranium oxide slurry as fuel now being developed by Westinghouse for Pennsylvania Power & Light Co., would seem to fall squarely in Strauss' second large-reactor category.

Reaction from at least one source in Congress was fast and furious. Sen. Clinton P. Anderson (Dem., N. M.), chairman of the Joint Committee on Atomic Energy in the past year, demanded to know why Strauss had changed position.

"We were disappointed that Strauss gutted the Joint Committee program last summer," he said. "Now he comes back with some of the same proposals we made."

There will be a vigorous effort by both Democrats and Republicans in the new Congress to get a "real program" going, Anderson forecasts, adding that "the enormous success of the British" will help this drive.

Neutral observers have pointed out that industry may have trouble trying to meet June 1962 deadlines on the advanced types of reactors Strauss selected for support; consequently, that either under the Gore program or the Strauss program the government may soon find itself building more reactors.

U. S. Uranium Reserve, Production Figures Disclosed; Declassification Also Affects Civil Power Reactors

Hard on the heels of its publication of enriched uranium prices (NU, Dec. '56, R2), AEC put out a wealth of data about U. S. uranium production and reserves. The information was made available under the new declassification guide (*see next column*).

Most significant numbers: the U. S. has known domestic uranium ore reserves of 60-million tons, compared with one million in 1948. Ore production for 1956 was about three million tons. Concentrate production for 1956 was 6,000 tons U_3O_8, but at an annual rate of 8,000 tons in December compared with a rate of 4,000 tons at the beginning of 1956. Production of U_3O_8 rose from 1,600 tons in the second half of 1955 to 2,600 tons in the first half of 1956, and 3,400 tons in the second half of 1956.

Information on uranium production prior to July 1, 1955, continues to be held classified, but observers estimated on the basis of the published figures that total production to date may be in the neighborhood of 12,000 tons of U_3O_8 = 10,200 tons uranium, = 714 tons U^{235}.

Twelve uranium mills are now in operation in the U. S., eleven of them privately owned and representing an investment of $50 million. Eight new mills costing $35 million were contracted for in 1956 for completion by early 1958.

Simultaneously, Canada for the first time published some statistics. Known reserves of ore are about 225 million tons. France also disclosed U figures (*see p. R9*).

A new declassification guide has gone a long way to make civilian power reactors a completely open, freely discussible subject.

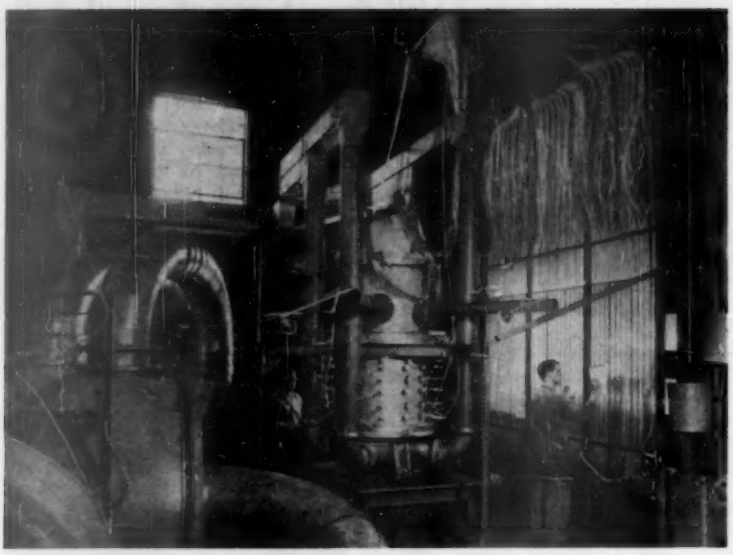
The tripartite (U. S., U. K., Canada) agreement will result in a large volume of technical information being released for publication, after material now classified has been reviewed in the light of the new guide. However it has already been announced that PWR, SRE, and HRT become declassified facilities under the new rules. Other items declassified are the technology of heavy-water production processes; zirconium-hafnium separation processes; the liquid thermal diffusion process for enriching uranium; statistics on uranium ore reserves and concentrate production; methods of reducing plutonium compounds to metal; all data on mass spectographs; and various data on radiation effects and chemical processing. Information on military and production reactors and on gaseous diffusion remains classified.

The new rules will permit the U. S. to cooperate effectively in the civil power field with friendly nations on an unclassified basis. This will greatly facilitate the negotiation of bilateral agreements for cooperation.

AEC said distribution of listings and abstracts, and printing of the most useful reports, would follow as soon as possible after the review, but that it would be "some months" before all information expected to be declassified would be widely available.

U. S. Uranium Mills

Name	*Location*	*Capacity (tons ore/day)*
In Operation		
Anaconda Co.	Bluewater, N. M.	3,000
A.E.C.	Monticello, Utah	600
Climax Uranium Co.	Grand Junction, Colo.	350
Kerr McGee Oil Industries, Inc.	Shiprock, N.M.	500
Mines Development, Inc.	Edgemont, S.D.	300
Rare Metals Corp.	Tuba City, Ariz.	250
Union Carbide Nuclear Co.	Uravan, Colo.	850
Union Carbide Nuclear Co.	Rifle, Colo.	280
Uranium Reduction Co.	Moab, Utah	1,500
Vanadium Corp. of America	Durango, Colo.	430
Vanadium Corp. of America	Naturita, Colo.	350
Vitro Uranium Co.	Salt Lake City, Utah	550
	total	8,960
Under Construction		
Atomic Fuels Extraction Co.	Bedrock, Colo.	200
Dawn Mining Co.	Ford, Wash.	400
Gunnison Mining Co.	Gunnison, Colo.	200
Lost Creek Oil & Uranium Corp.	Split Rock, Wyo.	400
Lucky Mc Uranium Corp.	Fremont County, Wyo.	750
Trace Elements Corp.	Maybell, Colo.	300
Texas Zinc Minerals Co.	Mexican Hat, Utah	775
Union Carbide Nuclear Co.	Rifle, Colo.	1,000
	total	4,025
	grand total	12,985



Quarter-scale PWR shows flow

Scale model of Shippingport reactor used in fluid flow experiments to see if coolant will circulate properly and give adequate cooling to all areas of reactor. Fans at left supply large amounts of air at 5.5 psi to model, simulating pressurized water flow in real reactor. On manometer board at right, technologists measure liquid level, and thus air pressure, at 350 places in model. Work is being done for Westinghouse at Battelle Memorial Institute, Columbus, Ohio

Bethlehem is interested in building merchant A-ship

Contrary to newspaper accounts, the shipbuilding division of Bethlehem Steel Co. is definitely interested in building the first nuclear merchant ship soon to be laid down—provided work is not to start on it simultaneously with the first nuclear surface warship for which Bethlehem already has a contract.

"We did not decline to build the merchant ship," R. H. Tingey, nuclear power manager for Bethlehem's Fore River shipyard at Quincy, Mass., told NUCLEONICS. "Actually we have not been asked to quote on it yet. If this ship comes along with sufficient time interval between it and the Navy's cruiser, we would be interested in bidding. We could not take it at the present time, however, because it would completely exceed the capacity of our design force at the moment."

A wire-service news story on Dec. 18 had stated that Bethlehem had declined to build the merchantman because of its commitment to build the cruiser.

Con Ed starts work at site

Ground was broken without ceremony for the Indian Point, N. Y., nuclear generating station at 12:15 pm Dec. 20 when Harvey Powell, an employee of Poirier & McLane Corp., began to axe down the first tree on the heavily-wooded site. Poirier & McLane has a contract to clear the site and build access roads. The station is scheduled to enter service in 1960.

FIR to Kaiser, American Standard

AEC is understood to be negotiating a $3.5-million contract for the Food Irradiation Reactor (NU, Dec. '56, R7) at Stockton, Calif., with Kaiser Engineers as prime contractor and architect-engineer, and American Radiator & Standard Sanitary Co. as core designer. Food Machinery & Chemical Co. will design an indium sulfate blanket and specialized equipment.

New Exposure Limit Asked To Protect Population

A new limitation on occupational radiation exposure, superimposed on existing levels, is being recommended by the National Committee on Radiation Protection.

On the basis of present evidence, NCRP has decided the most important new limitation should be one relative to gonadal exposure to individuals during their reproductive lifetime, committee head Lauriston Taylor told the American Nuclear Society. In effect, NCRP is shifting emphasis from exposure of the individual to exposure of the population, and from weekly or monthly exposure level to exposure accumulated over an individual's lifetime.

The new pattern retains the basic maxima of 0.3 rem/wk, the penalty allowance of 3.0 rem/13 wks, and the allowance of 15 rem/yr (allowing for 2 weeks' vacation). These basic figures are being made subject to a further limitation to insure that the dose is not accumulated too rapidly: persons over 18 may not accumulate a total dose in excess of 5 times the number of years over 18. This automatically holds down exposure at the younger, child-bearing ages where it is most critical, and allows more margin at the less critical older ages.

As Taylor explained it, the new concept implies building up a "bank" of reserve exposure that may be called on when needed. Thus a person starting work at 18 and receiving 1 rem/yr for five years has a total of 5 rem as compared with 25 permitted. He has "banked" a reserve of 20, and should occasion demand a larger dose, he may take up to 15 rem in the next year and still have a reserve of 5. Persons starting radiation work at an older age will have automatically built up a reserve and may take larger annual doses, up to the age pro-rated maximum. This procedure will permit elimination of the present rule allowing greater exposure for those over 45.

These levels are not modified by the allowance for an emergency exposure of 25 rem once in a lifetime, nor by radiation exposure received for medical reasons. The rules of Handbook 59 will be continued, but with yearly limitations of 5 rem to the blood-forming organs, gonads, eye lenses, and 10 rem to the skin.

The new "bank" formula was worked out, Taylor explained, to give greater protection against possible genetic effects on the population at large on a sliding-scale.

AEC Financial Report Tells Story of Growth

For what is believed to be the first time in its history, AEC has published and distributed its annual financial statement in booklet form. The 28-page pamphlet is a mine of information about AEC budgets, operations, projects, procurement, research, and even communities.

Covering the fiscal year 1956, the report illustrates why—and how—AEC operating costs increased 25% in that year, to $1.6-billion. Of this, $729-million (45.6% of the total), by far the largest part, went for production of enriched uranium and plutonium. $281-million (17.6%) went for uranium ore, and an equal amount for weapons development and fabrication. $177-million (11.1%) was spent on reactor development, $51-million (3.2%) on research in chemistry, physics and metallurgy, $30-million (1.9%) for research in biology, medicine, and cancer; and $59-million (3.7%) on administrative, community, and other activities. Most of these expenditures represent increases of from 11 to 48% over expenses the previous year.

Investment in plant rose from $6,487-million on July 1, 1955, to $6,713-million on June 30, 1956, as AEC's massive building program approached completion. Of this total, 81% is in production facilities (34.5% in gaseous diffusion plants, 23.4% in production reactors and separation plants, 4% in feed materials plants, 7.6% in weapons, and 11.5% in other facilities); 11.5% is in research facilities (7.2% in labs, 1.9% in reactors, 2.4% other); 4.5% in communities, and 3% miscellaneous.

Number of AEC employees stood at 6,583 at the end of fiscal '56 as against 6,013 for fiscal '55; but construction contractor employees dropped to 13,322 from 23,606, while operating contractor employees rose to 90,238 from 82,936.

Total spent by the U. S. government on the atomic energy program from June 1940 through June 1956 amounted to $13,847,200,000.

Charts on reactor development give breakdowns on amounts spent on various approaches. Of a total of $123.5-million spent from July 1, 1947, to June 30, 1956, on development and construction of experimental power reactors, $41.4-million went for pressurized water reactors, $14.6-million for boiling water types, $10-million on sodium graphite, $22.5-million on fast breeders, $33-million on homogeneous, $1.6-million on liquid metal fueled, and $400,000 on organic moderated.

Aircraft reactor development costs shot up to $49.6-million in fiscal '56, a 119% increase from the previous year. Cumulative costs on the project from 1950 through fiscal '56 were $138-million including both construction and research and development.

The naval propulsion reactor program has cost a total of $273.3-million since 1948. Development costs in fiscal '56 increased to $40.9-million, a 53% increase over the previous year. Construction costs were $9.8-million.

Stress Corrosion Cracks Delay Start-Up of HRT

Microscopic cracking, ascribed to stress corrosion, in the leak detector system of HRT may delay its start-up until the fall of 1957, AEC announced in Oak Ridge. The Homogeneous Reactor Test (sometimes also called HRE-2) was originally to have been completed last year, and until now had been thought to be on the verge of going critical.

The damage to the leak detector system was noticed during non-nuclear test operation. In addition, some evidence has been found of similar damage to pipe flanges in the high-pressure system to which the leak detector system is connected. The reactor itself is unaffected, however. Chloride ion contamination of stainless steel tubing is believed responsible (stress corrosion in the presence of Cl ions is an inherent problem with stainless steel, AEC pointed out, and is not specifically related to nuclear systems as such).

Source of the chlorine, NUCLEONICS learned, was in the stainless steel tubing used for the leak detection system, of which there is some two miles, and which had apparently been pickled at some time and had not been properly cleaned. HRT's builders went to great lengths to eliminate any traces of chlorine from getting into the main reactor system, but regarded the leak detection loops as mere auxiliaries and failed to inspect thoroughly enough.

Startup of HRT will be delayed somewhat in any case, as it has been decided to replace the leak detector tubing and some of the pipe flanges in the high-pressure system (i.e. core tank, circulating pumps, heat exchangers, pressurizers). Further non-nuclear test operation is being continued in January and February, and may result in a decision to replace all the high-pressure flanges and, as a precautionary measure, possibly also the flanges in the low-pressure system (dump tanks, catalytic recombiner). If this becomes necessary, HRT will not start up until fall.

Weaver Sees Experience on Large Plants Needed

"I think what we need more than anything else is some experience on large-scale plants," Charles Weaver, Westinghouse vice-president for atomic activities, told the Nuclear Energy Writers Association. "Nuclear power is still an art, and it will be many years before it becomes a science."

"We don't know enough now, so we overdesign," William Shoupp, his technical director, added. "As we learn more, we will be able to avoid overdesigning, and there's where cost reductions will come in."

Both men reported progress on the 150-Mw homogeneous power reactor the firm is developing for Pennsylvania Power & Light Co. "We have isolated the primary problem areas, and have made enough progress on them so we are very much encouraged," Weaver said. "Our strength in the homogeneous system is not shaken—on the contrary. We think it will make a splendid large plant."

On the other hand, he indicated Westinghouse had no interest in the natural uranium fueled, heavy water moderated type. "That is not a plant directed toward the future as a source of power."

AEC License Situation

Notice of proposed issuance of construction permit in 15 days: AMF Atomics, for a 5-Mw swimming pool for Industrial Reactor Laboratories, Inc., at Plainsboro, N. J., 12/29/56

Westinghouse, for the 20-Mw tank-type WTR (Westinghouse Test Reactor) near Waltz Mill, Pa., 1/4/57

Applications received: Daystrom, Inc., to build an Argonaut-type research reactor near Princeton, N. J., 12/11/56

ACF Industries, Inc., to export a 5-Mw tank-type research reactor to Ispra, Italy, for the Italian CNRN (National Commission for Nuclear Research), 12/12/56

U. K. Power Reactor Awards Hold Surprises

Details of the first industrial nuclear power stations announced for England and Scotland on Dec. 14 make Calder Hall look ancient, crude and tiny.

The General Electric Co.–Simon Carves consortium, awarded the station planned by the South of Scotland Electricity Board (NU, Dec. '56, pp. R2, S3, S9) in the biggest surprise of the announcement, has the least conservative design. This features a giant spherical reactor of double-skin construction 70 ft dia, coolant pressure raised to 150 psi (from Calder's 100), steam conditions jumped to 585 psi, 700° F (from 210 psi, 595°). Not only is the design the most unconventional of the bids based on Calder Hall: it is also cheapest and largest. Installed capacity for the two-reactor station has gone up to 360 Mw gross, 320 Mw net (from Calder's 184 gross, 150 net) with a surprisingly low cost of $300/kw installed. The world's largest Goliath crane—200 ft high and spanning 200 ft on its wheel tracks, with a lifting capacity of 300 tons—will straddle the reactor building during construction and lift a whole heat exchanger tower at once.

The two most highly-prized prestige-winning orders for the first two Central Electricity Authority stations go, as had been generally expected, to the Nuclear Power Plant Co. and the AEI–John Thompson group. The former will build the station at Bradwell, Essex. This design also uses a spherical reactor vessel, 67 ft dia, but of single-shell construction; raises coolant pressure to 130 psi, and steam conditions to 755 psi, 704° F. Installed capacity is 312 Mw gross, 300 net, and the cost unofficially estimated at from $336 to $390/kw installed.

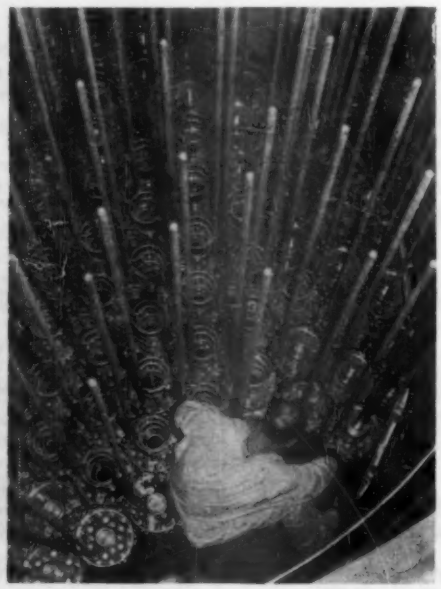
Smallest and most conventional is the design of the AEI–John Thompson group which will build the Berkeley station in Gloucestershire. This design retains the cylindrical pressure vessel, 50 ft dia × 80 ft high, but the operating characteristics are very different from the others. Gas coolant pressure is the lowest at 125 psi, and steam pressure is kept down to 306 psi, but the steam is superheated to 612° F. Installed capacity is 320 Mw gross, only 225 net. Cost given by the company is between $300 and $390/kw installed.

All three designs have gone to 3-in. plate for the reactor vessel, operate a dual-pressure cycle as at Calder, and provide for charging and discharging fuel elements while in operation, unlike Calder.

Construction of all three two-reactor stations is to start early this year for entry into service of at least the first reactors by 1960.

Negotiations—known to deal more with price than design—for the third CEA station at Inkley Point near Bridgewater, Somerset, are still proceeding between CEA and the English Electric Co.–Babcock & Wilcox group, thus far left out in the cold. This was a surprise, for EEC–B&W are doing the heat exchangers and civil engineering at Calder Hall and Chapel Cross, while GEC–Simon Carves had the least nuclear experience to date. Yet the GEC group is thought to have come up with all the modifications that AEA engineers would themselves have embraced were they to rethink Calder Hall.

Although a fifth nuclear consortium formed recently by Crompton Parkinson and Richardsons Westgarth may also bid for the Bridgewater station, it is considered likely that EEC–B&W will get that job. Announcement of that award has been postponed indefinitely, as also on a giant 550-Mw coal-fired generating station that Britain—not yet in a position to abandon conventional steam-plant development—is planning. Also postponed was an official government revision of the entire nuclear power program as originally set out in the White Paper of February 1955. However a statement in Commons indicated the government plans to spend between $1.96- and $2.02-billion in the next nine years. From this, observers have estimated that an additional three stations may be planned, for a total nuclear capacity of 5,200 Mw by 1965.



Last can for core

Technicians at Atomics International (NAA) lower last moderator can, left, into core of Sodium Reactor Experiment in Santa Susana mts. 30 mi NW of Los Angeles (NU, Nov. '56, R6). Can is fabricated of sheet zirconium, contains 10-ft-high block of graphite. Looking down into core, right, may be seen some of 119 moderator cans filling cylindrical core tank. Coils on top of cans guide uranium fuel elements into tube openings; pipes above cans control internal gas pressure. SRE is expected to go critical in early spring

Papers Wanted for Second Industrial Radiation Session

The second annual Industrial Nuclear Technology Conference will be held in Chicago, May 14–16 (not May 13–15 as previously announced). The first day of the Armour Research Foundation–NUCLEONICS sponsored meeting will be tutorial, the second two devoted to technical sessions.

For the latter, contributed papers are sought. They should be of about 20 minutes' duration, describing a particular experiment, technique or set of plans, in any area of applied nuclear technology with the one specific exception of nuclear power. They might well include purely basic results with speculation as to their implied import.

Send abstracts to L. Reiffel, ARF, 3440 S. State St., Chicago.

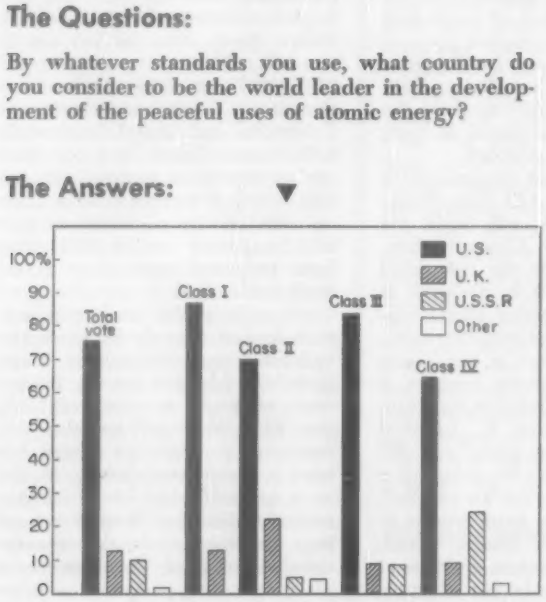
World Opinion Places U. S. In Nuclear Lead

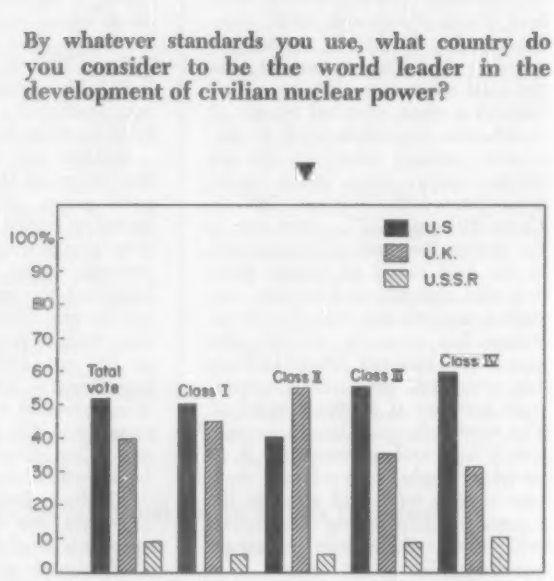
The Questions:

By whatever standards you use, what country do you consider to be the world leader in the development of the peaceful uses of atomic energy?

By whatever standards you use, what country do you consider to be the world leader in the development of civilian nuclear power?

The Answers:





Class I -- atomic energy officials
Class II -- industrial leaders now in atomic energy or priority customers for power reactors
Class III -- editors and opinion formers
Class IV man in the street

Editor's Note—Because the question of whether or not the U. S. is the world leader in civilian nuclear power development was thrust into the center of the domestic political arena in 1956, NUCLEONICS *conducted this special survey, not to prove any one viewpoint correct or incorrect but rather to gather pertinent data that may be useful in the policy debates that will inevitably arise shortly.* NUCLEONICS *correspondents polled four categories of people (as shown in the chart) in 11 countries: Australia, Austria, Brazil, France, West Germany, India, Italy, Japan, Lebanon, Mexico and Spain. Insufficient responses were obtained in England. The questions asked were aimed primarily at getting two pictures: how people rank the U. S., U. K. and USSR, and what people think of the U. S. atoms-for-peace program. Included at the end of the survey report are selected statements from some of the respondents. Editorial comment on the survey appears on p. 37.*

The United States is the recognized world leader in the development of peaceful uses of atomic energy, according to a special NUCLEONICS poll of atomic energy authorities, leading industrialists in the atomic field, editors and other opinion formers, and men in the street of 11 foreign countries of the free world.

Of the 102 persons questioned by NUCLEONICS correspondents, 75% said the U. S. led in development of peaceful uses of atomic energy generally. The U. K. received 13% of the first-place votes, the USSR was the choice of 10%, and 2% of the votes went to other countries.

But only 52% of those questioned thought the U. S. was the world leader in the development of civilian nuclear power. In answer to this question: "By whatever standards you use, what country do you consider the world leader in the development of civilian nuclear power?" the U. S. barely received a majority of the votes. The U. K. was second with 40%, and the Soviet Union was a poor third with only 8% of the votes.

Significantly, the USSR received its highest percentages of votes among editors and opinion formers (Class III) and men in the street (Class IV).

But of more importance to U. S. atomic planners is the breakdown of votes on the question of world leadership in civilian nuclear power development. Of atomic energy officials (Class I), 50% thought the U. S. was the world leader, 45% thought the U. K. was ahead, and 5% chose the Soviet Union. Class II voters (industrial leaders in the atomic energy field) also gave the Soviet only 5% of the first place votes on this question. However, the industrial leaders (who represent potential customers for power reactors) gave 55% of the first place votes to the U. K.; only 40% of their votes went to the U. S.

Class III and Class IV voters gave 56 and 58% of the first place votes to the U. S., 35 and 32% to the U. K. and 9 and 10% to the Soviet Union.

The poll was taken in October of last year, and the publicity associated with the opening by Queen Elizabeth of the Calder Hall station undoubtedly accounts for some of the increase in first place votes recorded for the U. K. However, as was noted above, the most significant swing in votes for leadership in power (as con-

trasted with peaceful uses generally) occurred in the class composed of industrial leaders now either in atomic energy or priority customers for atomic power reactors, where the straight publicity impact should be expected to be less than on technically-less-informed people. But the contrary is the case. Among Class II and atomic energy officials (Class I) the U. S. shows a percentage point drop of 30 and 37. Among editors and opinion formers the percentage point drop is 28 but among men in the street it is only 6 percentage points.

As was indicated, the Soviet Union atomic propaganda had its greatest impact on Class III and Class IV. It seems clear that the more highly informed groups, if responsive to publicity, are only responsive when there is a degree of solid accomplishment behind the publicity. Several questions were used to shed light on the knowledgeability of the respondents. Asked if they knew of any countries in the world now operating nuclear reactors designed primarily for the purpose of producing useful power, 77% said yes and 23% said no, some of the 77% voting "yes" listing more than one country. Relative to the total listing of countries, the U. K. received 31% of the mentions, the USSR 24%, the U. S. 22%, France 11% and 10% of the mentions were scattered among other countries.

The phrase "designed primarily for the purpose of producing useful power" was variously interpreted. Both the *Nautilus* and the MTR were listed by name as meeting the criterion, as were Calder Hall (which, although in operation, is designed primarily for plutonium production and generates electricity as a by-product), and Shippingport (which is not yet in operation). Because of the various interpretations given this phrase, it is difficult to draw meaning from responses to the follow-up questions: "What is the nuclear power being used for, in the countries named?" The belief was indicated in 78% of the responses that commercial power was being produced; 20% of the responses mentioned propulsion, heating or other such uses, and 10% of the answers indicated a research or experimental use.

Asked if they could name any countries now building large (50,000 kw electric capacity or greater) central station power plants, 80% said they could. The U. K. was listed 65 times, the U. S. was listed 64 times, the Soviet Union received 50 mentions, France 23, and all others received a total of 10 citations. No significant variation in percentage vote occurred among the four classes.

The survey also contained five questions concerning the U. S. international "atoms-for-peace" program. Of the persons queried, 74% were aware of the existence of such a program. Asked to specify what the program was, 29 gave no answers, 37 mentioned technical assistance or related matters, 22 specifically listed the supply by the U. S. of enriched uranium, 12 mentioned radioactive isotopes, 11 listed the term "bilateral agreements," 11 mentioned financial assistance, 9 mentioned exhibits, 8 listed research reactors, 6 mentioned the International Agency or international conference and 4 listed power reactors (some, of course, listing more than one item).

Asked "Do you feel the U. S. should be doing more than it is in its "atoms-for-peace" program, 68% thought so, 18% thought not, and 14% gave no answer. Scientists thought the U. S. was doing "too much already." When asked what more the U. S. should be doing, 38 respondents gave no answer, 18 indicated that the general peaceful uses should be increased, 18 thought bilaterals should be liberalized, 15 wanted more technical assistance, 13 thought information policies should be liberalized, 7 asked for financial help, 5 wanted help.

SOME COMMENTS FROM PERSONS INTERVIEWED:

Australia

Atomic energy official: "U. S. should open its doors to foreign scientists and reduce some restrictions. More publicity on 'atoms for peace' is required; sincerity of effort should be stressed."

Austria

Man in the street: "Too little information (on U. S. atoms-for-peace program) reaches the 'uninformed' group of the population." And, "More important than peace program is end of military tests in U. S., U. K., and USSR."

Brazil

Atomic energy official: "If more of our scientists could get into the climate of your atoms-for-peace program by studying the U. S. or by listening to U. S. instructors here in Brazil, we would be able to move ahead much faster, and clear up this political farce." And, "If the U. S. could spare some top professors or instructors and equipment (for a regional research center in Brazil), it would give Brazilians something to sink their teeth into instead of shouting politics about something they don't know."

France

Newspaper editor: "Any nation that has so much to offer the world as the U. S. does cannot content itself with the present effort on atoms-for-peace. Atoms-for-peace should be handled as a scientific program, which it is, rather than an advertising campaign, which it is not."

Germany

Atomic energy official: "The U. S. should leave irradiated fuel elements in the countries which could make use of them."

India

Newspaper editor: "Too much talk and too little of concrete acts. As atomic knowledge and information is freely available, the U. S. should take the lead in helping to set up all over the democratic world atomic plants for peaceful uses. The U. S. should take the lead in developing atomic energy for medicine, transport, industry, etc." *(Note: On the basis of "general impressions," this editor ranked the USSR first both in general peaceful uses of atomic energy and in developing civilian power.)*

Italy

Industrialist: "It seems to us that Britain has achieved in the field of reactors operated by natural uranium and by graphite a very advanced degree of technical performance, which will allow of immediate industrial results. . . . It does not seem to us that any of the types now being studied in the U. S. approached that level of development, as their plants are little more than experimental ones and in no case such as to be able to produce power in an equally near future at costs approximately competitive with those of power produced by the traditional systems. Looked at from this point of view, Britain should be classed higher than the U. S. It is, however, necessary to consider that the Americans have attacked the problem on a much wider front. . . . In our opinion, in a few years almost all the types of reactors now being studied in the U. S. will be able to attain that level of performance now attained by British technology in the single field of reactors using natural uranium, graphite and gas. We may indeed presume that some of the reactors the Americans are studying will attain an efficiency of installation and of operation economy that is precluded to the type in which Britain has specialized. . . . It seems to us therefore that the delay in American achievement as compared to that of Great Britain is for this reason justified, and we have therefore assigned priority to the U. S."

Japan

Atomic energy official: "The U. S. should provide fuel enriched more than 20%. We also want more freedom for chemical processing of spent fuel."

Lebanon

Industrialist: "We need able men abroad. The best men are picked by industry in the U. S. and leftovers are sent abroad. The U. S. should choose better experts to send abroad."

Mexico

Industrialist: "The legal code by which foreign nations can obtain enriched atomic fuel should be simplified."

Spain

Atomic energy official: "The U. S. should help in developing national techniques for fuel element manufacturing and reprocessing. There are too many restrictions on dissemination of technical knowledge in reactor technology."

Reactor News

200 MW BOILING REACTOR FOR NRTS

AEC has decided to build an $8.5-million addition to the Borax series of experimental boiling water reactors. To be called Arbor—for Argonne Boiling Reactor—the experimental facility will be built at the Idaho testing station, and will have a power level of 200 Mw (heat). This compares with 3 Mw for Borax-3, and 20 Mw (5 Mw electric) for EBWR at Argonne in Illinois. However no electricity will be generated with Arbor, which will consist of a reactor core and pressure vessel, steam condensers, heat exchangers, pumps, valves, controls and auxiliary equipment. Argonne National Laboratory will be responsible for conceptual design of the entire facility and detailed design of the core, controls and instrumentation; an architect-engineer, not yet named, will design the building and other features of the system. Arbor is expected to be ready in late 1959. Principal purpose is to study the effects of the different parameters that can be varied on reactor stability and power density; to study variations in pressure, in forced circulation rates and in subcooling at the inlet; to study any combination of cycles: direct, indirect and dual; and to study various means of control—both by bypass as on EBWR and by other schemes.

BATTELLE SETS UP PHYSICS UNIT

A reactor physics division has been established to coordinate the increased volume of reactor research under way at Battelle institute. It will conduct research in four fields: radiation effects and exponential experiments, reactor design development, theoretical reactor design analysis, and heat-transfer studies. Joel W. Chastain, Jr., will be director.

TWO FIRMS TO SELL ARGONAUTS

Daystrom Inc. and American Radiator & Standard Sanitary Corp. are both getting into the Argonaut business. Daystrom's nuclear division has filed for a construction permit to build and operate the Argonne-developed training reactor (NU, June '56, 22) near Princeton, N. J. (The division plans to break ground shortly for its new reactor-building plant.) The machines will be sold under the trade-name "Dart." American Standard is building its first one at its Redwood City, Calif., headquarters, will adapt it especially for college and university use training nuclear engineers.

SECOND CALDER REACTOR CRITICAL

On Dec. 12 the second reactor at Calder Hall went critical. Output will be up to full capacity early in the new year.

ARMOUR REACTOR BACK IN OPERATION

Problems arising from unsatisfactory operation of the gas recombination system in the Armour Research Foundation reactor have been licked by Atomics International, builder of the 50-kw water-boiler. The reactor, first started up last summer (NU, July '56, R10), is back in operation after AI solved the trouble by relocating entry ducts of the oxygen "sweep gas" that carries off hydrogen and oxygen (products of water dissociation in the core) to the recombiner. Prior to the revision of the gas flow pattern, minor detonations, presumably due to the presence of undiluted H and O above the core solution, were observed at power levels between 3 and 5 kw.

BELL LABS PLANS A CP-5

The Air Force, having asked Bell Labs to expand its program of nuclear physics research, plans to provide a modified CP-5 similar to the MIT reactor (*see p. 38*) which Bell will set up at its Whippany, N. J., lab site. No contractor has been selected yet, but it is hoped to start construction "fairly early this year." The AF will also supply a 3-Mev Van de Graaff.

NDA TO DESIGN BELGIAN TEST UNIT

Nuclear Development Corp. of America has been chosen to design and develop Belgium's second reactor, an engineering test reactor of advanced concept, by the Centre d'Etudes pour les Applications de l'Energie Nucléaire. CEAN is sponsored jointly by the government, industry and universities, runs Belgium's nuclear research center at Mol (NU, Feb. '56, 13). BR-2, scheduled to start up by mid-1959, is described by NDA as a "third generation" experimental reactor, drawing as it will on 15 years of reactor experience—on the as-yet unfinished ETR and ORR as well as on MTR and CP-5. CEAN personnel are already working with NDA at its two Westchester, N. Y., labs.

NEW CRITICAL ASSEMBLY AT LASL

There are at least 10 critical assembly machines at Los Alamos Scientific Laboratory, the lab has revealed. Newest, "Hydro," differs from the other low-power air-cooled devices in that it is water-cooled and can operate at power levels up to 3 kw; it is also the first portable critical assembly at LASL, and can be used outdoors, avoiding scattering effect from surrounding walls. It is being used as an intense source of neutrons. Other machines mentioned for the first time include Honeycomb, Planet, Scripto, and Little Eva. Only three had previously been announced: Jezebel (NU, Oct. '48), Godiva (a bare assembly), and Topsy, recently dismantled.

PROGRESS ON DRESDEN BLUEPRINTS

GE reports that plant arrangement designs are nearly 100% complete and construction designs 25% finished for the Commonwealth Edison Dresden station (*sketch* NU, Nov. '56, R8).

U. S. LEASES U-235 TO JAPAN

The second U. S. lease agreement to provide fissionable material to a foreign country (first since the Geneva exhibit reactor was sold to Switzerland) was concluded with Japan. Under it the U. S. will provide uranyl sulfate solution containing 2 kg U^{235} (contained in U at 20% enrichment) for Japan's first reactor, a 50-kw water boiler being built by Atomics International for the Japan Atomic Energy Research Institute's research center at 75 mi NE of Tokyo. AI announced that the first shipment of components for the reactor is on its way to Japan. It comprises 63 items to be installed underground within the concrete shield, including electrical equipment, assemblies for gamma radiation experiments, and other experimental apparatus.

World News

France Reveals Uranium Statistics

Uranium resources in metropolitan France are estimated at from 50,000 to 100,000 tons, Secretary of State for Atomic Affairs Georges Guille said. The unexpected disclosure of details about France's U-mining program preceded that of the U. S. by less than a week (*see p. R2*). In addition to her home deposits that make her the largest U producer in western Europe, France has rich resources of urano-thorianite in Madagascar: veins now being worked amount to 1000 tons of a grade yielding 10–20% U and 60–70% Th. Prospecting teams have also made promising strikes in the Sahara. U production in 1957 is expected to be 300 tons; in 1958, 500; in 1961, 1,000; in 1970, 2,500; in 1975, 3,000 tons. This will require an expenditure of $170-million besides some $56-million already invested. By 1975 7,000 persons will be needed to meet these production goals, triple the present personnel. Other disclosures: the ore concentration plant at Gueugnon (Saône-et-Loire) has an annual concentrate capacity of 500 tons, handling 50,000 tons of ore/yr. Cost at Gueugnon is estimated at $34.32/kg, to which the refining-to-metal operation at Le Bouchet near Paris adds $14.30/kg. Two more concentrating plants for lower grade ores are being built, one at Escarpière (Vendée) to produce 400 tons of concentrate from 300,000 tons of ore annually, another at Bessines (Haute-Vienne) for 450 tons of concentrate from 200,000 tons of ore.

Vienna Prepares Quarters for Agency

Provisional headquarters for the International Atomic Energy Agency have been leased by the Austrian government and are now undergoing reconstruction. The buildings—the Vienna Merchants' Sanatorium, located near the wine-gardens—served as HQ and station hospital for the U. S. Forces in Austria from 1945 to Oct. 1955. They will be ready for IAEA occupancy in July. A modern building is planned for IAEA's permanent home at Cobenzl, on the eastern edge of the Vienna Woods, and a housing committee formed by leading banks will build 200 apartments for IAEA staff.

Brazil Names AEC Members

President Kubitschek has named five members to the new Brazilian Nuclear Energy Commission, to serve under Adm. Octacilio Cunha, named chairman earlier (NU, Nov. '56, R11). Observers say the new commission represents a very solid group of Brazilian scientists and diplomats. They are: Foreign Service Minister Otavio Augusto Dias Carneiro, an MIT graduate with a combined scientific and diplomatic background; J. Costa Ribeiro, a leading figure in Brazil's old Atomic Energy Commission that was under the National Research Council; João Maffei and Bernardo Geisel, also members of the predecessor group and professors of physics and chemistry respectively; and Francisco Humberto.

Atomic NATO Proposed

Unatom, an economic and scientific organization of free world nations for atomic development, patterned after the North Atlantic Treaty Organization, has been proposed by John Jay Hopkins, head of General Dynamics.

U. K. Farming Out Fusion Work

Thermonuclear research in Britain has entered a new phase: contracts to carry out aspects of this work have been allotted to a number of firms and universities who will work in collaboration with the A. E. A. This is a new program of broadened industrial participation; a few firms and universities had been engaged in controlled fusion work for some time.

U. K. Industry Forms Trade Association

N. E. T. A. C.—Nuclear Energy Trade Associations' Conference—has been formed to establish liaison within British industry in matters relating to nuclear energy. Founder-members are the British Chemical Plant Manufacturers' Assn., the British Electrical and Allied Manufacturers' Assn., the British Engineers' Assn., the Scientific Instrument Manufacturers' Assn., and the Water-Tube Boilermakers' Assn. Membership is open to trade associations concerned with nuclear equipment.

Germans Seek British Reactor

The Parliament of North Rhine–Westphalia has asked the State government to order a 10-Mw/Dido-type materials testing reactor in Britain, for the West German nuclear research center to be built at Königsforst near Cologne. The North Rhine–Westphalian State had previously ordered a 5-Mw pool-type Merlin from Associated Electrical Industries of London (NU, July '56, R1; Oct. R10).

India Sets Price for Heavy Water Plant Work

Vitro Engineering Corp., technical consultants for the Indian government's $52-million D_2O plant at Nangal in the Punjab, will be offered $1.6-million total fee for setting up the heavy water section of the plant if the catalytic exchange process is used, $1.3-million if hydrogen distillation is used. The plant is to produce 7.5 tons a year.

Cuba Plans to Start Shortly

Marcelo Alonso, secretary of the Cuban AEC, has announced work on a 10-Mw power reactor will begin shortly. This came after Cia. Cubana de Electricidad, an American & Foreign Power subsidiary, had placed on record the firm's intention to install the 10-Mw nuclear station in Cuba. However Havana has yet to initiate discussions with Washington for a power bilateral.

Tractor A-Plane for Long Hauls?

One conceivable solution to the problem of using a reactor at take-off and landing was suggested by Gordon R. McGregor, president of Trans-Canada Air Lines, who broached the idea of a nuclear-powered air tug to which conventional passenger planes could be engaged and disengaged. The air tractor would be capable of towing at tremendous speeds. Speculation has been that the first A-planes would also have conventional engines for use near the ground.

New Program in Israel

The Israeli government is working out a new program providing for the establishment of a nuclear industry, NUCLEONICS learns. The first stage of the program will involve expenditure of $28-million.

Nordic Group Holds First Meeting

Representatives of Denmark, Finland, Iceland, Norway and Sweden attended the first meeting of the Nordic Atomic Research Committee in Stockholm, to discuss establishment of a joint Nordic research institute in Copenhagen and a reactor training center in Oslo.

ROUNDUP

Report from Germany

BONN

The future of nuclear energy in West Germany, including West Berlin, is clouded by a number of factors that cannot yet be accurately assessed. It seems that Germany is marking time, at least as far as a concrete direction is concerned, until sometime late in 1957.

Germany faces a national election sometime next year. If the present regime of Chancellor Konrad Adenauer is returned to power, the industrial application of nuclear energy will probably stay in industry hands. Should the Social Democrats win, or come to power as the major party in an SPD-dominated coalition, it is possible that a degree of state control over nuclear energy may be introduced into the German scene. German industry claims the Socialists will nationalize atomic energy as a foothold, only to go on progressively to other sectors of industry. No qualified reporter of the German scene will yet commit himself as to the probable outcome of this contest, expected before September 1957.

Another factor contributing to the German lag is that a national atomic energy law probably will not be passed before the summer of 1957. The law, in turn, is tied closely to the future of OEEC and Euratom.

Then, too, there are widely-differing philosophies as to how fast industry should proceed.

These are the elements in the West German atomic situation:

The German Ministry for Atomic Affairs is a small organization. Housed in a former hotel on the banks of the Rhine in Bad Godesberg, the ministry numbers only 100 people, "from the Minister to the charwoman," as one official put it wryly. It can operate with such a small staff because much of its real work is done outside, primarily by a 25-man Atomic Energy Commission, a private body without executive powers composed of government officials, scientists, businessmen, bankers and labor union officials (NU, March '56, 23). The commission operates with five committees: law, research and training, technical and economic questions involving reactors, radiation protection, and financial and social problems. All told, some 300 persons work on its committees and working groups.

The ministry's budget for this year is about $10 million, but $25 million has been requested for 1957. The bulk goes to universities, technical colleges, laboratories, and for uranium prospecting. The ministry also aids in financing research reactor projects.

German industry, generally, insists on paying for everything it buys in the nuclear field. Industrialists see this as one way of maintaining independence of government control. But the ministry and industry cooperate closely in planning for and obtaining research and power reactors.

In the power reactor field, the Germans expect to go their own

way. They will slavishly copy neither the British nor the Americans. It is thought unlikely here, for example, that they will buy a Calder Hall type reactor.

Power bilateral talks between Germany and the U. S. will start in the spring of 1957. In addition to research reactors (NU, Oct. '56, R10), the Germans intend to buy a modified materials testing reactor, and a power demonstration reactor of 10 Mw (electric) for the Rheinisch-Westphälische Elektrizitätswerke (RWE) of Essen. They may buy another reactor for ship propulsion purposes to be used by the Hamburg group studying the utilization of nuclear energy for shipping.

In each of these cases, the Germans will probably not buy the complete plants. They hope to do much of the work on the conventional side themselves and buy only fuel and control devices from the U. S.

The RWE reactor will need 300 kg of 10% enriched uranium for its first charge and 5–10 tons natural uranium. Annual burnup is estimated at 18 kg of U^{235}. A boiling-water type reactor designed jointly by the AMF Atomics and Mitchell Engineering combine stands a good chance of being accepted as final choice.

German efforts in the power reactor field must be viewed against the background of the nation's progressively worsening power shortage. Informed sources say the Federal Republic's annual mean increase in power consumption was 6.2% for the period 1925–1955; it must be emphasized, however, that the post-war years 1945–1955 showed an average increase of 15.7%. Estimates of power needs by 1965 range from 152 to 180 million kwh. Considering only presently-available sources of energy, German experts forecast an energy shortage of 10–30 × 10^9 kwh by 1965 and of 20–60 × 10^9 kwh by 1970. This shortage can only be overcome by using sources of energy not now available —i.e., atomic energy.

German sources say the State Department in Washington is reluctant to hold power bilateral talks with the Germans now because the Department would prefer to conclude power agreements with Euratom rather than with individual nations.

Euratom. It is no secret in Germany that industry is not too keen on Euratom. Prominent officials in the field put their position this way: "In principle, we accept Euratom. We are for anything that will speed up European integration now. But we violently object to two Euratom provisions: First, that we would have to buy and sell uranium exclusively through Euratom. We would like to be free to talk bilaterally with other nations about our uranium supply. We dislike the idea of being tied to another state monopoly for the supply of a vital raw material." While Euratom would allow Germany to buy uranium outside the agency if there were a uranium shortage or if the price were too high, the Germans do not seem to feel that these two escape clauses are sufficient for their needs. It is thought likely in Bonn, however,

that the nation will accept Euratom as a political concession, primarily to the French, and that objections of German industry will be sacrificed to the ideal of Franco-German cooperation and integration.

The second objection to Euratom concerns the pooling of patents. A provision states that all atomic energy developments on the civilian sector may be acquired by Euratom, but that military developments remain the property of the individual nation that developed them. The Germans feel this imposes grave inequalities. Since military applications of atomic energy are banned in Germany, the Germans say they will be compelled to disclose everything they do. In the case of France, the Germans feel, a military iron curtain on exchange of information may be dropped at any time, allowing the French to keep certain developments to themselves under the pretext that they have military application only.

Germans Prefer OEEC

While the Germans feel that Euratom will definitely come into existence, they say they would prefer to work with an agency like OEEC. Their reasons are that OEEC would be more "democratic and liberal," but they admit that an OEEC set-up would take more time to establish than Euratom. On the other hand, it is acknowledged in Bonn that Euratom's "more dictatorial policies" would probably speed the construction of capital facilities.

Since Germany estimates that she will be able to produce only 20 tons of U/yr, insufficient for the long haul, Euratom's provision on buying only through that agency is apt to be highly unpopular here. In fact, the Germans are now holding exploratory talks with the Canadians about the purchase of uranium ore.

Government sources state that the U. S. is unwilling to sell natural uranium to the Germans, but is ready to sell special nuclear material: this would permit the U. S. to maintain a closer check on what is done with the material. For this reason, the Germans are apparently hesitant to tie themselves too closely to U. S.-furnished U^{235}, possibly because they would have no way of knowing when this source of supply might be cut off completely.

There have been reports that German and French firms are holding exploratory talks on construction of a gaseous diffusion plant, but no details are yet forthcoming. It is more than probable that the German firm Degussa is involved.

It is difficult to tell at this time where the real push for faster development and exploitation of atomic energy in Germany is coming from. It is known that State Secretary Brandt of the state of North Rhine-Westphalia is impatient to get going on all fronts, especially on power reactors. Brandt reportedly feels that closer cooperation with the British might be one way for the Germans to get started more quickly.

German industry is of two minds on how fast to proceed. The older men, still in absolute control of their firms, are willing to sit back and wait for future developments. The second-echelon management type, however, who will be in charge of German industry in another ten years, is more anxious to push ahead quickly.

It is known that most major German firms today maintain regular, active research staffs in nuclear energy. Very little is known about the work of these groups, but they have certainly not been idle these past few years. It should be remembered that these groups were, according to their own present-day boasts, active long before Allied permission for such work had been granted.

The Germans are not overlooking possibilities in the export market that may arise within the next few years. As one expert put it: "What we would like to develop, perhaps in close cooperation with American industry, is a small, light reactor that can be put on a plane, flown to its destination, assembled and put to work in a minimum of time. This is the type of reactor that would do a real job in the so-called underdeveloped countries." In cases like this, the Germans envisage the U. S. providing the fuel elements and the German firms providing the necessary accessories such as boilers and control devices.

Generally speaking, one gets the impression that the Germans cannot and will not push ahead too fast in the nuclear energy field. First, there is the question when an atomic energy law will be passed. Second, the Germans are sitting out final word on the future roles of OEEC and Euratom. Third, there are the two schools of thought in Germany on how fast to proceed in this field. Finally, Germany is suffering from a progressively worsening shortage of qualified engineers and scientists, which may prevent the nation from playing the role in nuclear energy to which her research and development abilities have, in the past, pointed her.

Staff Training Big Obstacle For Asian Nuclear Center

Primary emphasis in the Asian Regional Nuclear Center project must be on training nationals of the cooperating countries (the Colombo Plan countries) to staff the center, according to the survey report undertaken for the U. S. International Cooperation Administration by a team under the leadership of Marvin Fox of Brookhaven (NU, March '56, 24; April, 23). The center will be established in Manila with the aid of a U. S. contribution of $20-million.

"Recruitment of well-qualified scientists will be a major problem," the report states. "The total staff, including students, is expected to increase, in phase with the ultimate, long-range growth of the program, to a stable level of about 1,000. In the initial phase, the number of students at all levels that could be accommodated at one time would be about 200. While eventual staffing by scientists and technicians of the region is imperative, much of the early key staff will have to be drawn from western countries.

"Because of the critical shortage of technically trained people, even to some extent in Japan, India and Pakistan, an education and training program must be undertaken. During the early years, emphasis would be on this training, and on immediate applications of atomic techniques to regional problems. A student training program, to begin immediately upon authorization of the center, is proposed. Special training of prospective scientific staff members should also be initiated as soon as possible. On this basis, the establishment of an Asian Nuclear Center is considered to be entirely feasible, and capable of contributing significantly to the scientific and technological development of the region."

The Brookhaven report recommends the center be endowed with a general purpose research reactor having an average thermal flux of $10^{14} n/cm^2/sec$, such as an enriched uranium, light-water moderated and forced-cooled unit with graphite reflector. This could be bought in the U. S. for $3-5-million, it adds. Other facilities, in addition to labs and equipment for research in the basic sciences, should include a hot lab, radiation sources, isotope labs, extensive special facilities for application studies in medicine, agriculture and industry including a research hospital, and ultimately a demonstration power reactor.

News in Brief

Union Carbide Forms Research Institute

Union Carbide Research Institute has been founded to do basic scientific research, Union Carbide & Carbon Corp. announced. A large lab to be built near Tarrytown, N. Y., to house it will be completed by early 1958. E. R. Jette, former head of the chemistry and metallurgy division at Los Alamos, will be director.

Sylvania-Corning Eyes Andover, Mass.

Sylvania has taken options on a 150-acre site at Andover, Mass., as proposed location for a $5-million nuclear research and production center. Sylvania acted pending formation of Sylvania-Corning Nuclear Corp., now in process of organization (NU, Dec. '56, R6). The center, which will concentrate on development and production of fuel elements and components, is to start operation in early 1958. Five buildings totaling 150,000 ft² will be built: a production facility, a pilot production facility, an advanced engineering lab, a service and maintenance building and an administration building. Initially the center will employ 300 (100 professionally trained); of these, half will come from Sylvania's present Bayside, L. I., lab and from Corning's nuclear staff at Corning, N. Y. The rest will be locally recruited. Employment is expected to rise to 800–1,000 in five years.

New Thorium Producer

Heavy Minerals Co., a subsidiary of Crane Co., Vitro, and Pechiney of France, is going into thorium production this month at its Chattanooga plant. Output will include oxide for nuclear fuel, as well as other forms for varying industrial uses. The firm joins Lindsay Chemical Co., Maywood Chemical Works, and Rare Earths, Inc., in the thorium field. Rare Earths was absorbed in a consolidation move last month by the parent company, Davison Chemical Co., itself in turn a division of W. R. Grace & Co.

New Hf-Zr Separation Process at U. S. I.

U. S. Industrial Chemicals Co. division of National Distillers has obtained an exclusive option on an Australian process for separating hafnium from zirconium chloride. The difficulty of separating the two similar metals has been a major factor in holding high the cost of reactor-grade—i.e., hafnium-free—zirconium. The process, eliminating the cumbersome chemical extraction step, is now in pilot-plant stage at U. S. I.'s Cincinnati research labs. If it proves commercially feasible, U. S. I. plans to use its option to buy world-wide patent rights.

Martin Completes Gamma Facility

A 5,500-curie Co^{60} gamma source facility has been opened by Martin Co.'s nuclear division in Baltimore. The source, installed at the bottom of a 6-× 6-ft, 12-ft-deep pool, will be used to test radiation effects on materials. It is the second gamma source installed at Martin, and was built entirely with private capital for industry use.

Indiana D_2O Plant Off Stream

AEC is shutting down one of its two heavy water plants. The Dana, Ind., facility is being placed on standby, as forecasts of D_2O demand indicate that the Savannah River plant will alone be able to meet requirements in the next few years. The shutdown will be spaced over nine months, beginning in early spring. Dana, begun in June 1950, made the first D_2O moderator for the Savannah River production reactors. The newer D_2O plant at Savannah River was built with more corrosion-resistant materials. DuPont operates both for AEC. Shutdown at Dana follows sale of the Trail plant (NU, Dec. '56, R12).

Niobium Capacity Increased

A $6.5-million tantalum-niobium plant is being built near Muskogee, Okla., by Fansteel Metallurigcal Corp. of Chicago. Construction is already underway and completion is expected by midsummer. The new facility will increase by 150% Fansteel's niobium capacity. The exotic metal (also called columbium) is coming into demand as a reactor material (NU, Oct. '56, R5).

New Boron Carbide Plant

Norton Co. dedicated a plant at Huntsville, Ala., last month to make a variety of electric furnace materials. Two among them, boron carbide and fused zirconia, are also in demand as nuclear materials—the former in control rods and shielding, the latter as starting raw material for Zr metal. Norton also became the fifth U. S. company (Sylvania, AMF, Koppers and GE's Carboloy dept.) to be authorized by AEC to exchange civilian atomic energy information and services under the bilateral with Canada. In Norton's case this involves technology of fabricating control rods, shielding materials, ceramic fuel elements and crucibles.

Course in Metallurgy for Power Reactors

Starting Feb. 4, Brooklyn Polytechnic will offer a spring term course on metallurgy of reactor materials, to be taught by Marcel Cordovi of Babcock & Wilcox and Henry Hausner of Penn-Texas Corp.

Peaceful Atom Exhibit for Brooklyn

Springtime in Brooklyn this year will feature two new expositions on peacetime achievement of atomic energy. From March 25 to April 21, the Brooklyn Public Library will offer the first New York showing of AEC's new "Atoms for Peace" traveling exhibit prepared by Oak Ridge Institute of Nuclear Studies. During the same month, the Abraham & Straus department store will stage a supplementary "Atoms for You" display with the cooperation of the Atomic Industrial Forum; the city Board of Education will arrange tours for teachers and classes.

Six Universities Picked to Aid ORSORT

As part of the program to double the capacity of the Oak Ridge School of Reactor Technology (NU, Sept. '56, R7), six universities have been selected to handle the first semester of ORSORT's one-year course. They are Carnegie Tech, Case Institute, Northwestern, UCLA, Florida U., and Union College in Schenectady. Each will have a two-year contract to take at least 20 students per semester, enabling ORSORT to raise throughput from 120 to 240 a year.

Aerojet-General Organizes Course

A concentrated one-week course for reactor operators and engineers was given last month for the first time by Aerojet-General Nucleonics at its San Ramon, Calif., plant. Seven experiments with the AGN-201 reactor and 22 lectures cover the reactor field. The course will be repeated periodically; tuition for individuals is $250.

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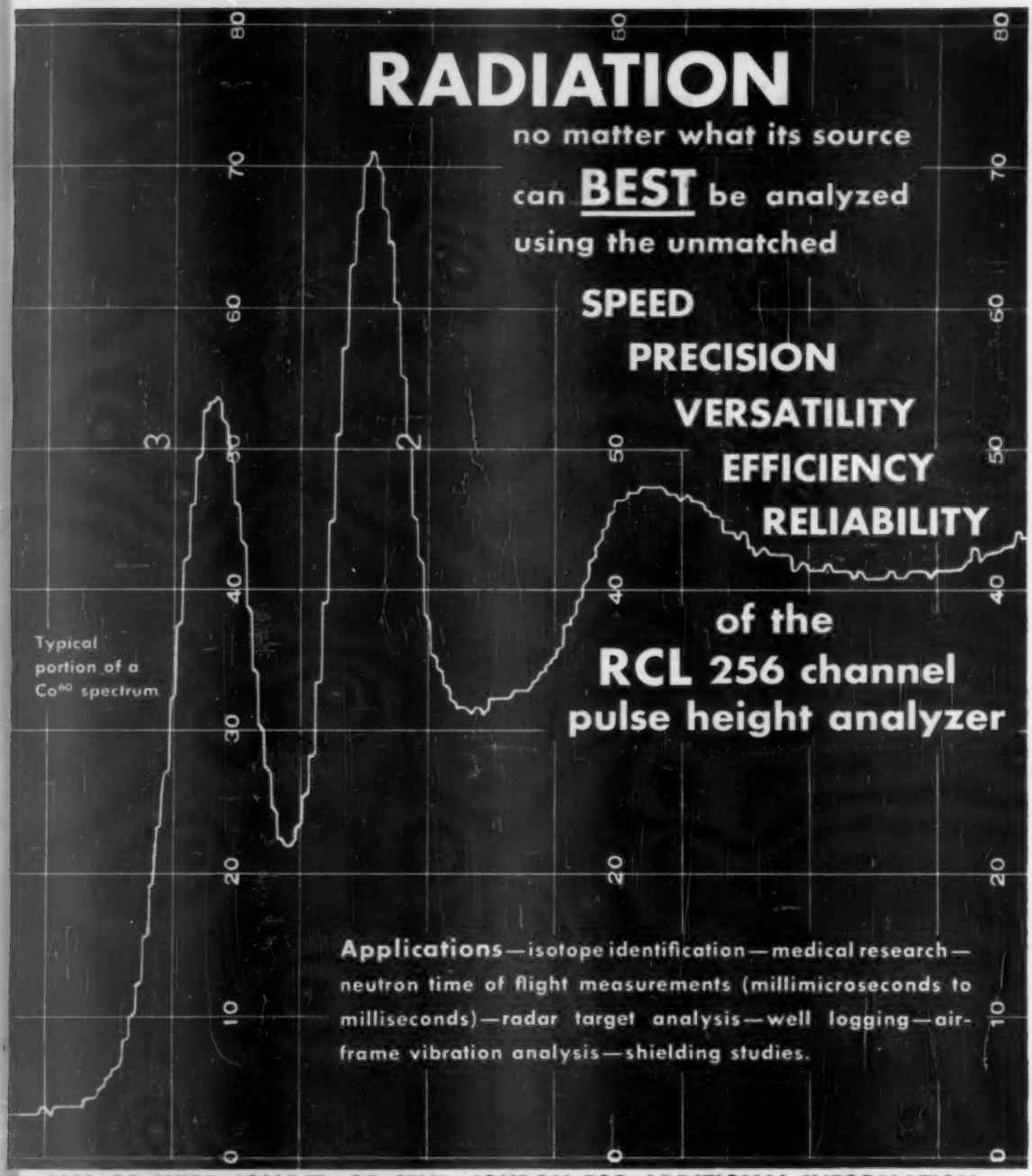

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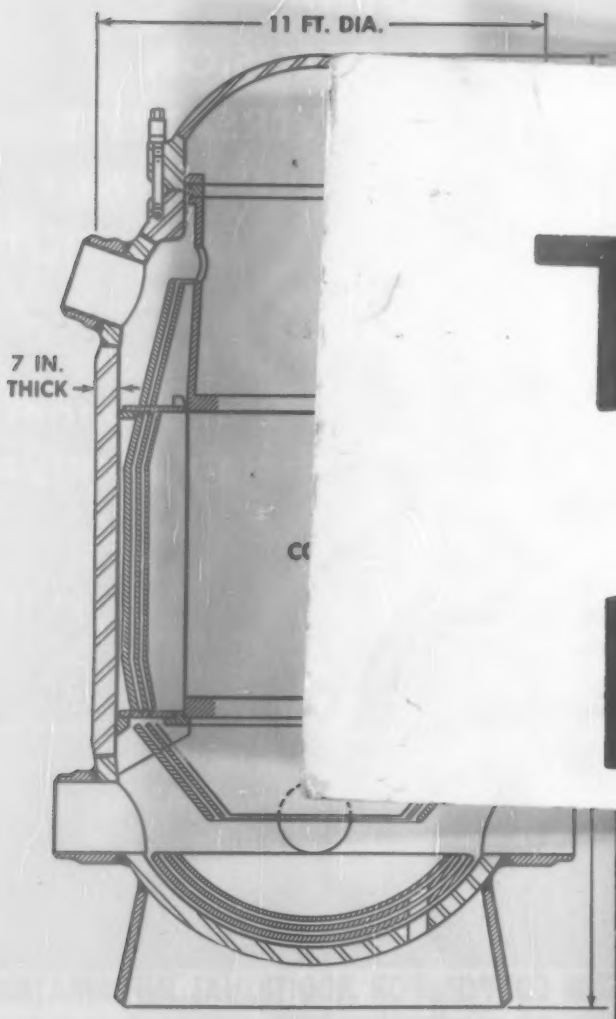

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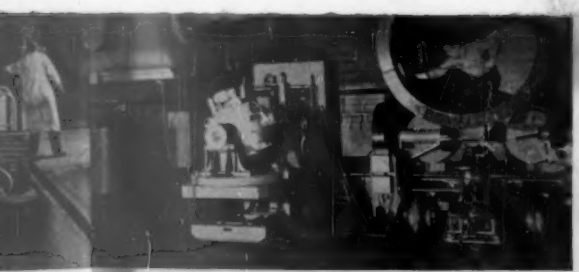

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Gamma ray sources have been used by B&W for radiographic examinations of weld seams in pressure vessels for many years. X-ray examinations, by machines of up to 2-million volt strength, are also used.

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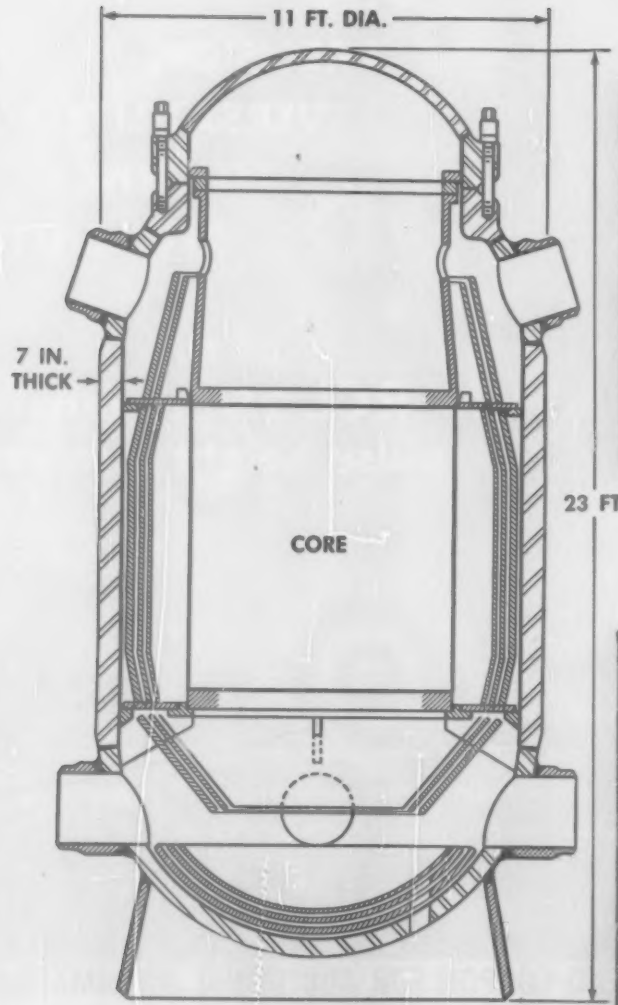
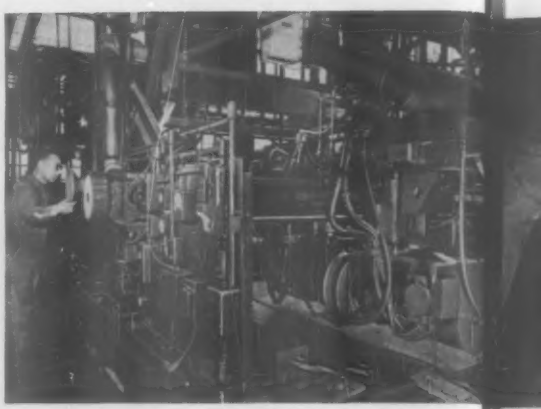
ATOMIC ENERGY DIVISION

B&W Pressure Vessels



REACTOR VESSEL



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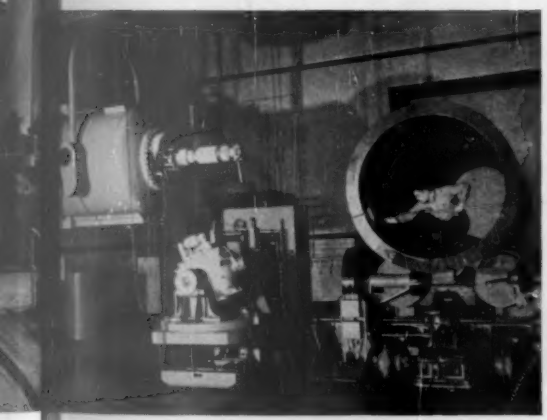

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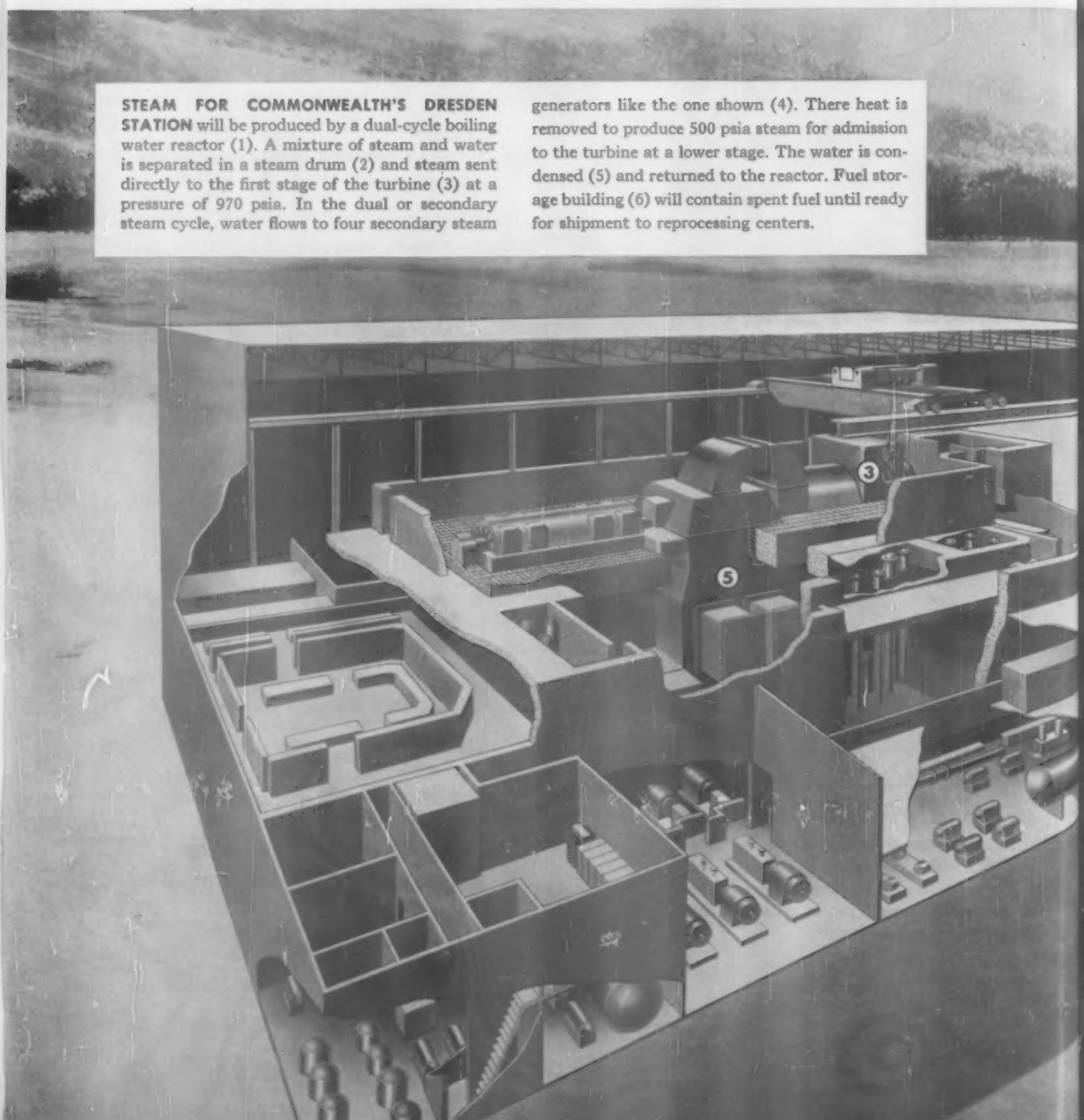
PROGRESS REPORT ON DRESDEN STATION

General Electric moves into final design stage on Dresden Nuclear Power Station



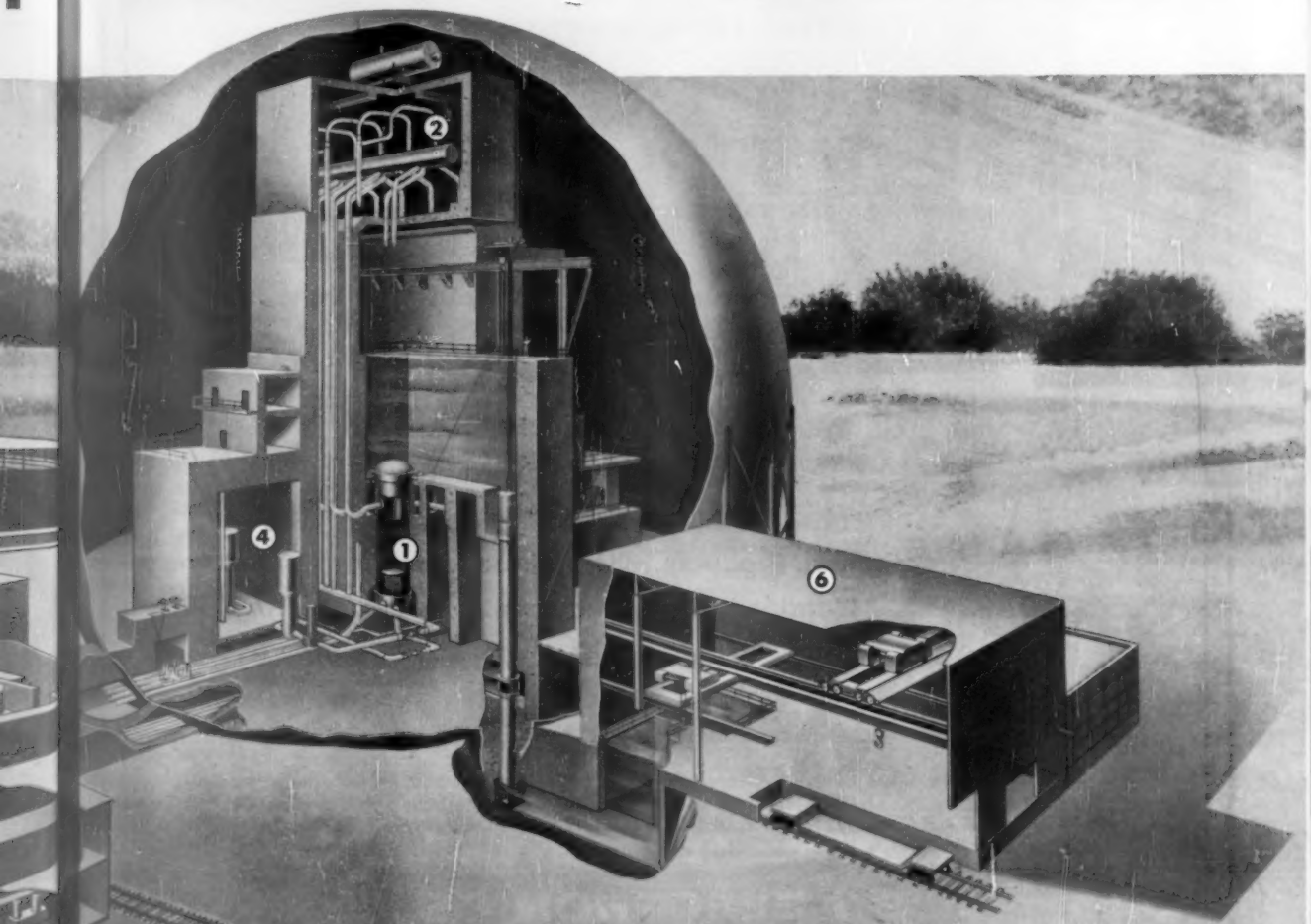
STEAM FOR COMMONWEALTH'S DRESDEN STATION will be produced by a dual-cycle boiling water reactor (1). A mixture of steam and water is separated in a steam drum (2) and steam sent directly to the first stage of the turbine (3) at a pressure of 970 psia. In the dual or secondary steam cycle, water flows to four secondary steam generators like the one shown (4). There heat is removed to produce 500 psia steam for admission to the turbine at a lower stage. The water is condensed (5) and returned to the reactor. Fuel storage building (6) will contain spent fuel until ready for shipment to reprocessing centers.

Work to finish final design on Commonwealth Edison's Dresden Station is progressing rapidly. Preliminary and design scope work has already been completed. Detailed construction designs are now 25% accomplished on the dual-cycle boiling water electric generating plant which will supply 180,000 kilowatts of electricity for Chicago by 1960.

Manufacturing is already under way as orders for major components—the 400-ton reactor vessel, a 190-foot-diameter sphere, turbine-generator, primary steam drum, secondary steam generators, and recirculating pumps—have been placed. Test loops have been built and experiments are being run to pretest some of the station's components.

After months of intensive design work, General Electric engineers and scientists report progress on the world's largest all-nuclear power station proceeding "on schedule." Atomic Power Equipment Department, General Electric Company, San Jose, California.

FOR FURTHER INFORMATION contact your nearest General Electric Apparatus Sales Office or write to: General Electric Company, Section 192-9, Schenectady, N. Y. for bulletins GER-1301, "The Dresden Nuclear Power Station"; or GER-1287, "A Review of Boiling Water Reactor Plants for Atomic Power Generation."



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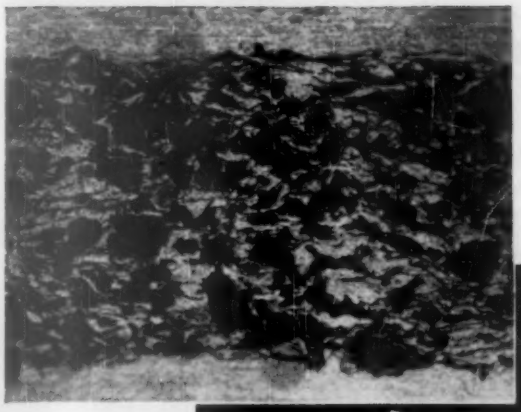
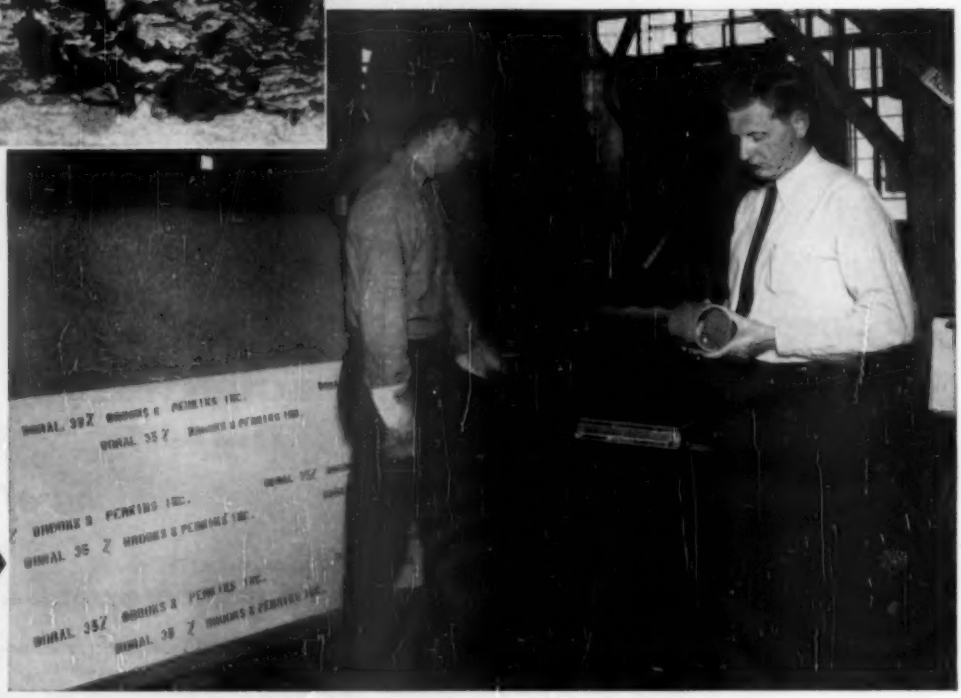


Microphoto of cross section, boral plate ¼" thick, 10 X Magnification. Crystalline structure of boron-carbide is shown in center; aluminum cladding on top and bottom.



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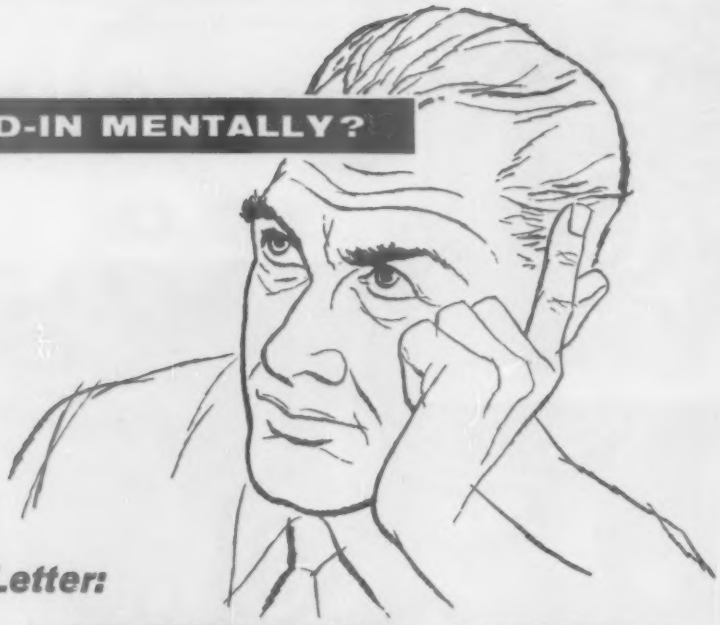

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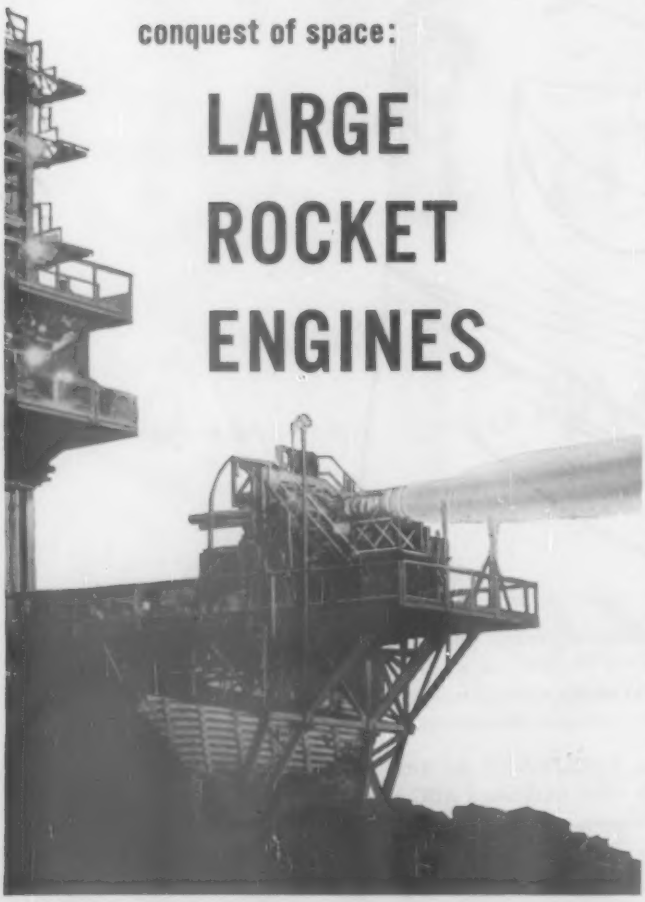

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GEORGE P. SUTTON, in the 13 brilliant years since receiving his MSME, Cal Tech, has made rocketry a way of life. His reputation is world wide. His book *Rocket Propulsion Elements* is recognized as the standard text on the subject. Still active academically, but no bookworm, he takes time off occasionally to study the laws of motion at some of the world's better ski resorts.

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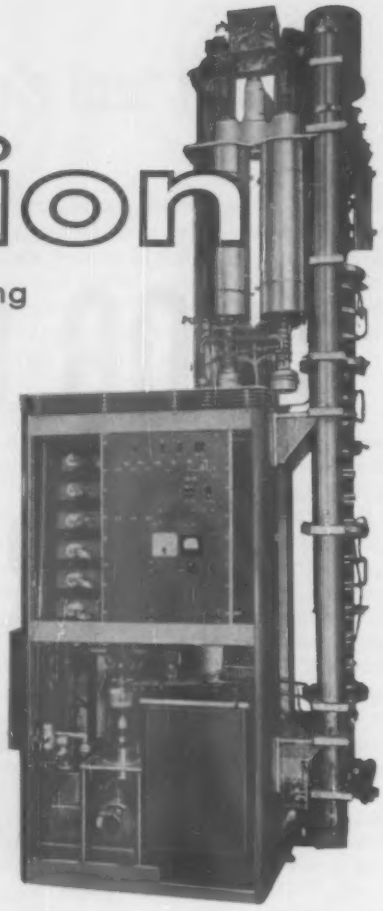

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Brief Specifications - ARCO Accelerators

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High Current Neutron Generators	
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Max. Beam Current	400 μa
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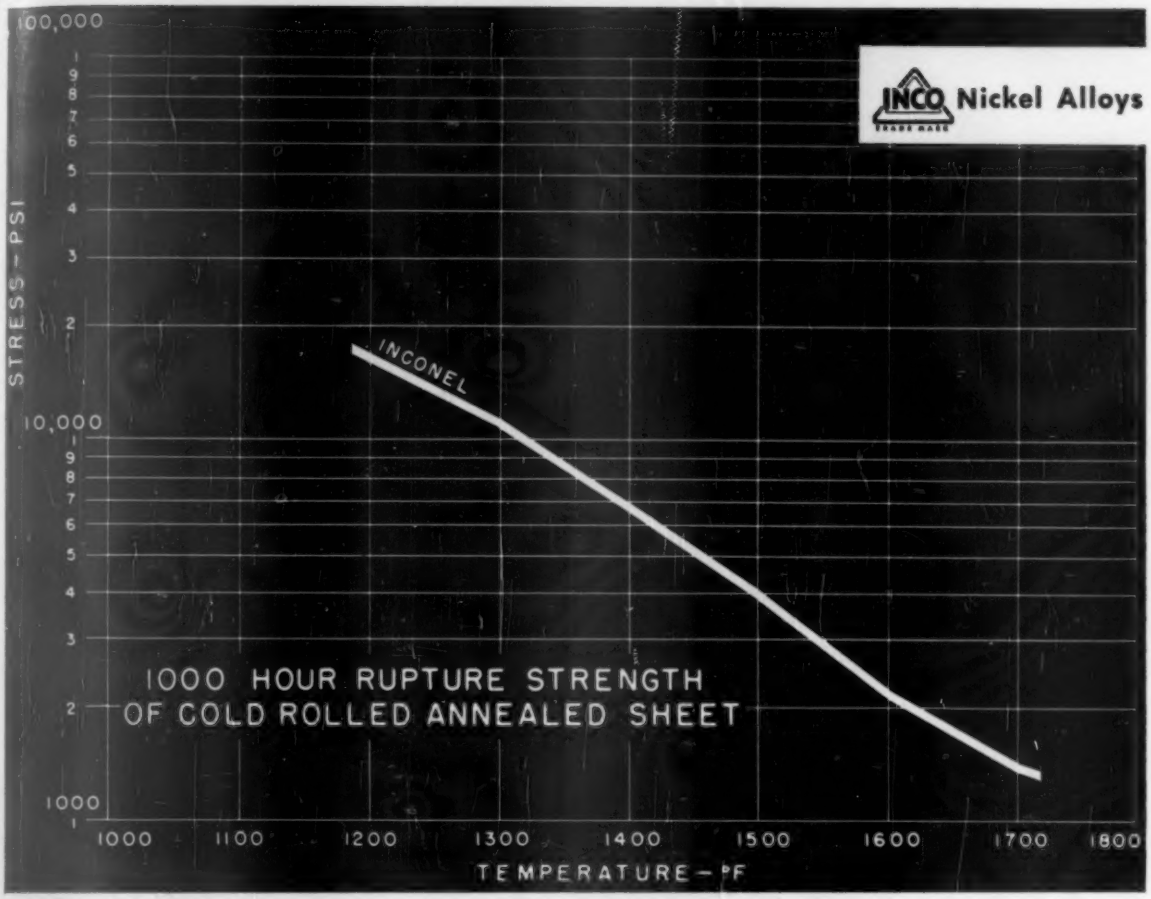

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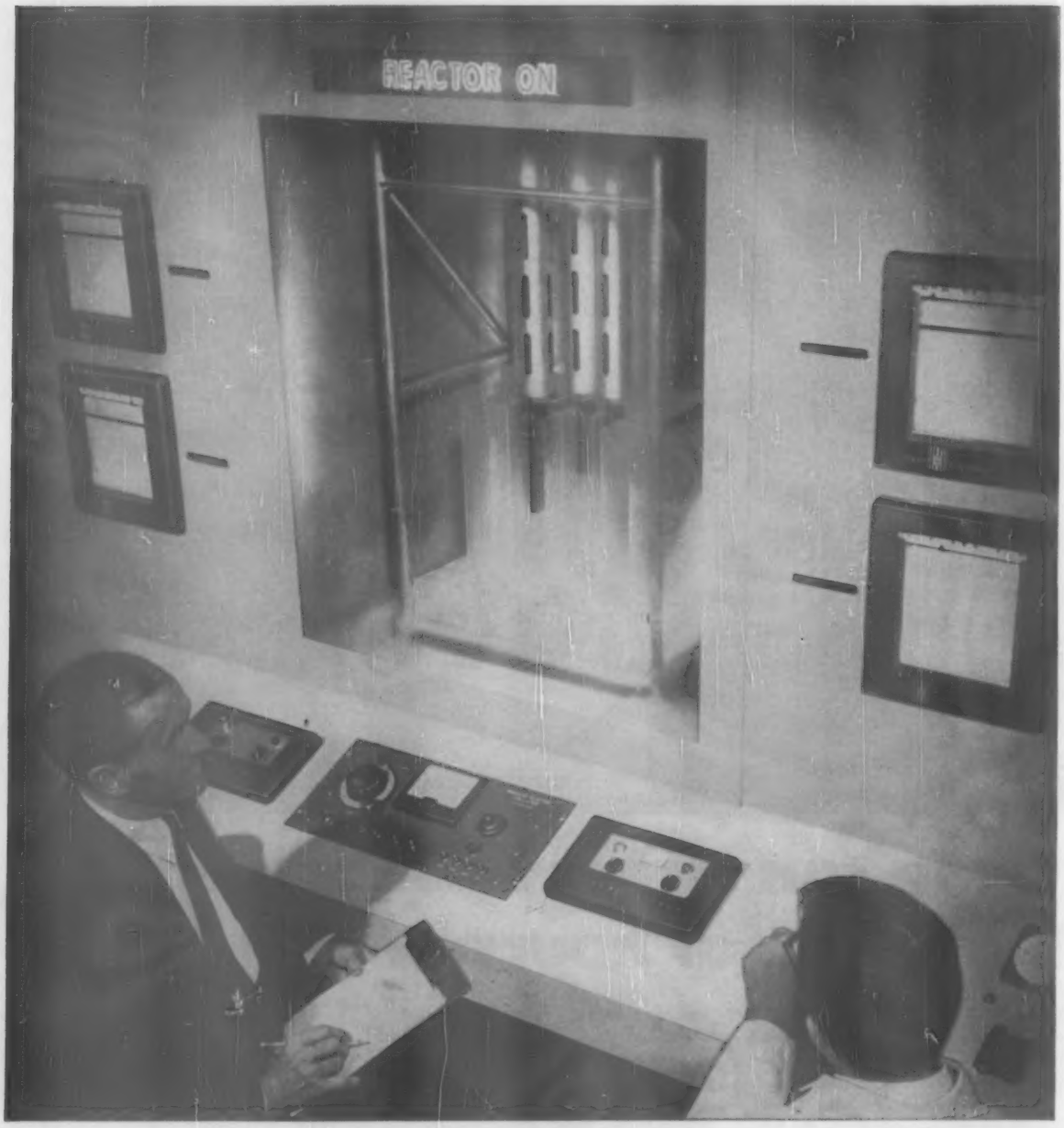

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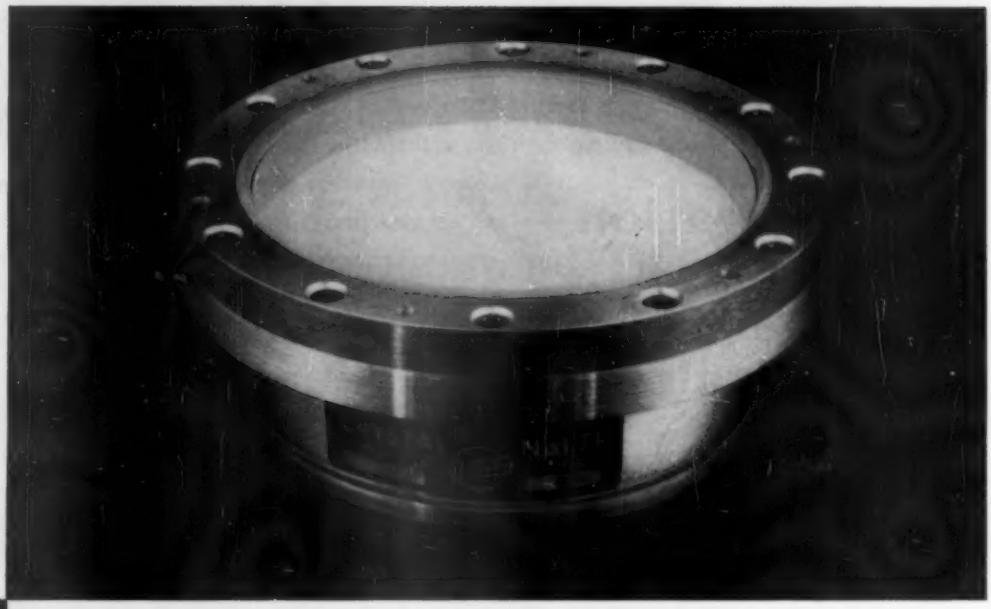

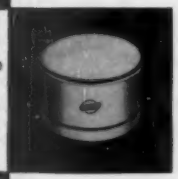

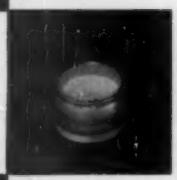

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U.S.I. CHEMICAL NEWS

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Greenleaf to Handle Market Development of Zirconium And Titanium for U.S.I.

William C. Greenleaf has been named Manager of Metals Development for U.S.I. and will be responsible for market development and sales of zirconium and titanium sponge, to be produced from U.S.I.'s two new plants now being built in Ashtabula, Ohio.

A recognized authority in the field of zirconium and titanium, Mr. Greenleaf presented three papers during the 1955 Atomic Industrial Forum Zirconium Program, describing (1) melting of zirconium, (2) fabrication of zirconium, and (3) zirconium mill products and prices. He also conceived and developed processes now in general use for producing both wide-sheet and flat-bar titanium and zirconium by continuous strip-mill techniques.

Faye Named Manager of Sodium Product Sales

Martin Faye has been named Manager of Sodium Product Sales for U.S.I. and will be responsible for coordinating sales and sales promotional activities for metallic sodium, "U.S.I. Isosebacic" acid and related products.

Mr. Faye joined the U.S.I.-National Distillers organization in 1952 in the Market Research and Development Department.

TECHNICAL DEVELOPMENTS

Information about manufacturers of these items may be obtained by writing the Editor, U.S.I. Chemical News.

A zirconium-copper alloy now available is reported to combine high electrical conductivity with good strength retention at elevated temperatures. Suggested for electrical motor commutators serving above 500°F where strength is needed. Conductivity is 95.8% of copper. **No.1193**

Titanium wire cloth is now on the market in sizes from 60 mesh to coarser grades. It is reported to be particularly suitable for filtering or screening highly corrosive materials. **No. 1197**

Zirconium and Titanium Lick Roughest Corrosion Problems

Metals to be Available at Lower Cost in Future; Provide Long-Lived Materials of Construction; Complement Each Other on Corrosion Resistance

It is now practical to fabricate equipment which is *corrosion-resistant to almost every substance encountered in industry*, by using either zirconium or titanium metal. Alloys of either metal, or possibly both, may extend the range even further.

Industrial applications of these metals have been hampered by two considerations: availability and price. Zirconium will shortly be produced at a rate sufficient to supply industrial needs, and titanium has been available to industry during the past two years. And it is expected that increased production of these metals during the next few years will result in significant price decreases.

Twelve to thirteen thousand tons of titanium were available in 1956 and present construction schedules indicate that the figure will rise substantially in 1957. U.S.I.'s new plant alone will add 5,000 tons to the annual production capacity by the end of the year. Zirconium will be on the market in quantity by mid-1957. When its new plant at Ashtabula, Ohio gets under way, U.S.I. will be able to supply 500,000 pounds or more per year to commercial users in addition to its Atomic Energy Commission commitments of 1,000,000 pounds per year.

New Metals Economical

Chemical process equipment can now be fabricated from titanium for a little over twice the price of stainless steel, and it is expected that in the future titanium equipment will be only 50-75% higher than stainless. Commercial grade zirconium equipment will probably be priced only 75-100% higher than stainless when volume production is reached.

Typical Corrosion Resistances* of Zirconium and Titanium

Corrosive Media	Metal Resistance	
	Zirconium	Titanium
Sulfuric Acid	excellent to good below 80%	good below 5%
Nitric Acid	excellent	excellent
Hydrochloric Acid	excellent	good below 10%
Phosphoric Acid	excellent to fair below 85%	poor
Chromic Acid	excellent	excellent to good
Aqua Regia	poor	excellent
Wet Chlorine Gas	poor	excellent
Chlorine Water	excellent	excellent
Sodium Hydroxide	good below 90%	good below 50%
Ferric Chloride	poor	excellent
Calcium Chloride	excellent	excellent
Cupric Chloride	poor	excellent
Sodium Chloride	excellent	excellent
Ammonium Chloride	excellent	excellent
Aluminum Chloride	excellent	excellent to fair

*Above data do not cover all conditions because of space limitations. Literature references may be obtained by writing the Editor, U.S.I. Chemical News, 99 Park Ave., N. Y. 16, N. Y.

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PRIOR TO SHIPMENT, this General Electric a-c electromagnetic pump was given a final mass spectrometer leak test. Manufactured by G.E. for Argonne National Laboratory's EBR-2 reactor test project, this unit can deliver 5000-gpm—highest flow any a-c linear induction-type pump has yet delivered.

Design experience in electromagnetic pumps pays off as . . .

General Electric builds 5000-gpm electromagnetic pump for Argonne Laboratory

The Argonne National Laboratory, operated by the University of Chicago for the Atomic Energy Commission, recently installed a General Electric a-c electromagnetic pump which can deliver 5000 gallons of liquid metal a minute—the highest flow yet delivered by an a-c linear induction-type pump. This unit will be used in Argonne Lab's EBR-2 (Experimental Breeder Reactor) test program.

General Electric's Medium Induction Motor Department is known as the outstanding manufacturer of large, zero-leakage, a-c electromagnetic pumps.

E-M pumps have a column of liquid metal which replaces the rotor of the conventional a-c motor. Thus, without rotary motion, the pumps provide quiet, dependable operation with virtually no maintenance. E-M pumps will operate in any position. Critical problems involving shaft warpage, bearing failures, and faulty bearing seals are eliminated. General Electric electromagnetic pumps can now be built for a wide range of uses in liquid-metal laboratories, power reactors, and industrial chemical processes. 873-5

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NUCLEONICS JANUARY, 1957

Jerome D. Luntz, *Editor*

U. S., the World Leader in Nuclear Power

UNFORTUNATELY or not, the development of atomic energy throughout the world is being carried out under the influence of political motivation. This has brought some benefit. Specifically, there was a great deal of political inspiration behind such things as the Geneva atoms-for-peace conference, the International Atomic Energy Agency, various bilateral programs, and even the fact that some countries have atomic energy efforts at all. These, to us, are atomic "goods."

On the negative side of the ledger, however, is something that has caused considerable confusion in the minds of people throughout the world and may yet distort the direction of technological development in atomic energy. This is the elusive—or perhaps unrealistic—question of who is the world leader in civilian nuclear power.

It's a mythical question because there can be no real agreement on the basis for determining leadership. In fact, it is widely recognized that there are very basic differences in motivation between different national programs. Thus, no all-encompassing formula for comparison can be developed.

But still the question is raised. And so NUCLEONICS feels obligated to jump into the fray, because whether or not people think the U. S. is in the lead affects two important matters: the favorableness of environment presented to American industry in selling to an export market, and the success of one facet of our atoms-for-peace effort.

OUR opinion is that the U. S. has the most important reactor program in the world. And it is the one that is having—and will have—the greatest impact on the reactor thinking of every country in the world, including the U. K. and the U. S. S. R.

This may be a bold statement to make but it is one that has a substantive basis. For one thing, it is fully recognized most everywhere that the U. S. does have the broadest and deepest reactor development program. There is nothing to compete with it.

Even in countries such as England and France, at least 90% of whose efforts have been on gas-cooled reactors, there shows through their optimism and hopefulness about gas reactors the realization that their nuclear futures will undoubtedly depend on other kinds of reactor systems. They openly admit their inability to spend much time right now on things that may be important to them in the future. And so, to back up their own efforts, they're watching ours very closely.

There is, however, much more direct and immediate an effect of the U. S. program on the efforts of some other nations. Many are spending the next several years getting their feet wet in nuclear technology, training their people, and, in general, getting a feel for what's going on.

Belgium perhaps provides the sharpest example of what will be happening elsewhere. The Belgians are in the process of setting up a long-term reactor program. At the moment, they have at least two major activities in mind: starting the building of a 100,000-kw power reactor in the next several years and looking far ahead toward the erection of a fast breeder power reactor. On the latter, they have sent a small team to work with the Detroit Edison group in the U. S. As far as the 100,000-kw plant is concerned, they have established a timetable for selecting a reactor type based on the timetable for progress in the U. S. program. The impact of our effort could be no greater.

IT would only be fair to point out, however, that the impact of U. S. reactor activities is not recognized as fully throughout the world as we would like it to be. This is borne out in the special NUCLEONICS opinion survey reported on p. R6, where it is shown that, although the U. S. is considered to be the world leader in civilian nuclear power development, this lead is marginal and, in one case (among industrial leaders), nonexistent.

Thus, we think the U. S. is falling down on what we think is an important purpose of the U. S. atoms-for-peace effort—that is, that, in addition to giving substantive nuclear aid, the U. S. should be convincing the peoples of the world that this country is in fact the world leader in the field.

Part of the difficulty in molding world opinion is that the British speak with one voice about their lead in nuclear power. On the other hand, the U. S. presents a widely divided front, with some of our leaders supporting the U. K. view and others opposing it.

At the least, although we recognize that U. S. leaders won't ever speak with the same voice on this subject, identification of standards of judgment should be made clear in public utterances. The Italian statement on p. R7 certainly puts the matter fairly.

In addition, the U. S. must recognize another very important factor in the attitude of foreign atomic energy people toward us. This is the very basic technico-political question of enriched versus natural uranium for nuclear power. Although the weight of technical judgment in this country seems to be in favor of enriched uranium, there is no little argument about this. Abroad, many countries do not yet have the technical basis for making their own decisions and so are influenced by political considerations, principally the desire not to be tied to the U. S. as possibly the sole supplier of enriched fuel.

Regardless of the merits of these arguments, it behooves us to make both paths as attractive to others as possible. As proposed by AEC Chairman Strauss last month, the U. S. should vigorously pursue the development of natural uranium systems. In addition, we should make it as easy as possible for countries to get enriched uranium with the fullest assurances possible of continuity of supply.

It will be through such means that the U. S. will strengthen its position as the real world leader in the field of civilian nuclear power.

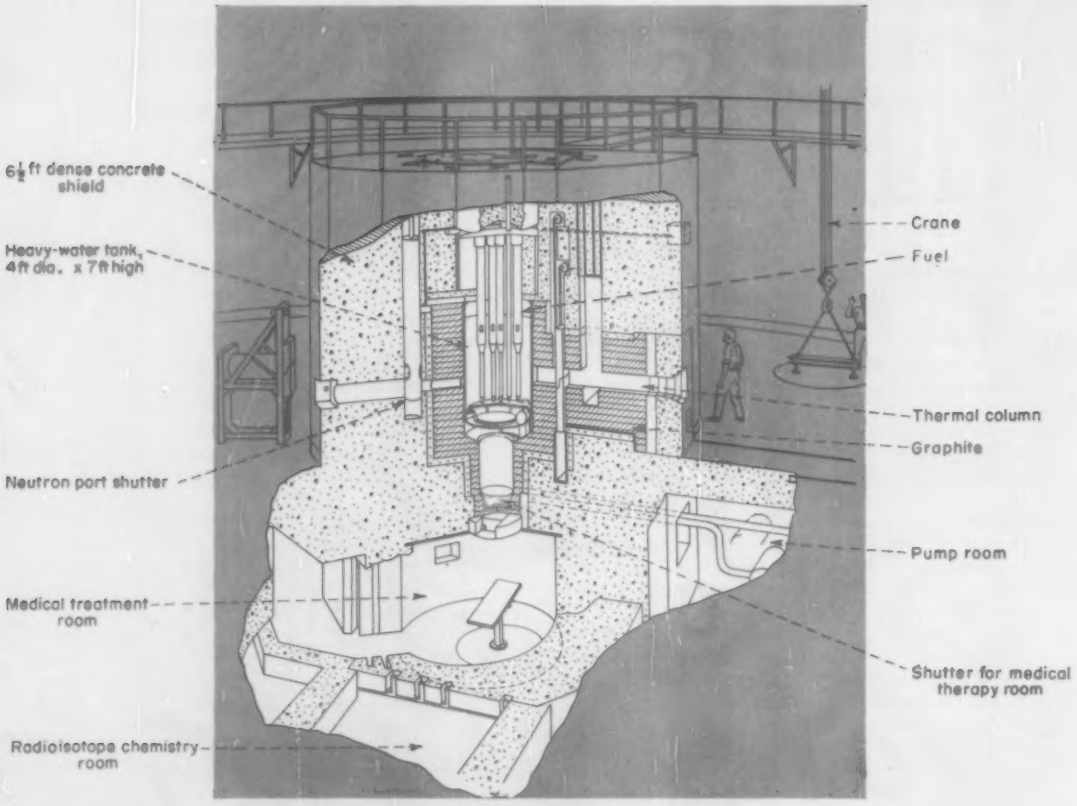

FIG. 1. D_2O inventory of MITR is about 10,000 lb. D_2O flows into plenum at tank bottom, upward through fuel element, and out into tank through holes shown in elements above and in Fig. 2. It then passes down through tank, out of reactor, and flows in a closed loop through heat exchanger at a rate of about 700 gal/min. In passing through reactor, D_2O rises from about 94° F to 104° F

MITR: The MIT Research Reactor

10^{13} flux available at 1 Mw, a variety of experimental ports, a core array designed so that fast flux can be increased in selected ports, and a medical facility having 10^{10} slow flux with a background of only 10^7 fast flux and 100 r/hr gammas are features of this new heavy-water reactor

By T. J. THOMPSON and T. CANTWELL
Massachusetts Institute of Technology
Cambridge, Massachusetts

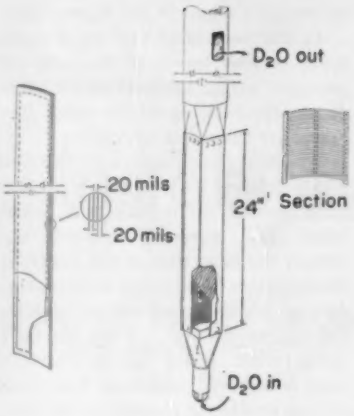

FIG. 2. Fuel elements used in MITR are exact replicas of the 18-plate MTR elements, except that the two outside plates contain no fuel and top attachment directs D_2O flow as in CP-5. Plates are curved and edges are brazed into heavier Al side plates. This element is used in MITR because of large surface for cooling and long history of reliable operation

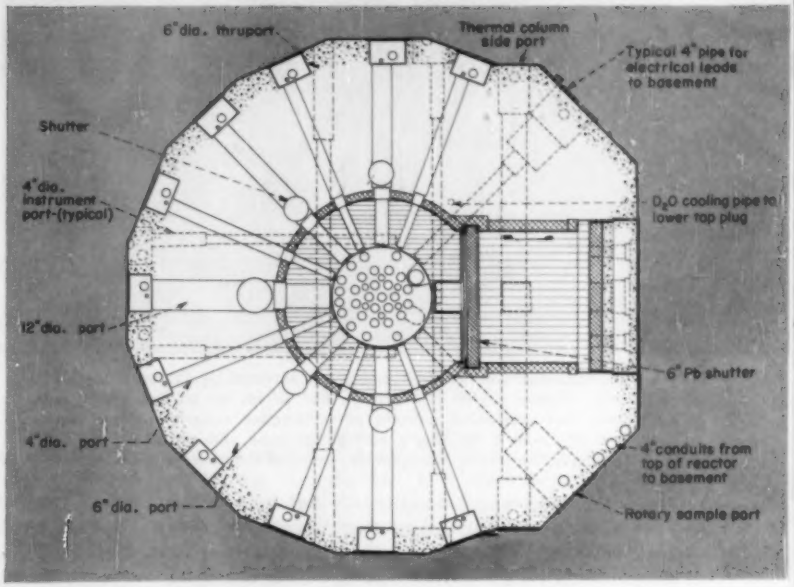
6" dia. thruport
Thermal column side port
Typical 4" pipe for electrical leads to basement
Shutter
4" dia. instrument port-(typical)
D_2O cooling pipe to lower top plug
12" dia. port
6" Pb shutter
4" dia. port
4" conduits from top of reactor to basement
6" dia. port
Rotary sample port

FIG. 3. Cross section through MITR at port level shows core grid (with ocations for fuel placement to increase fast flux at selected ports), shield, and a number of the experimental ports

A HEAVY-WATER COOLED and moderated reactor is being constructed for research and educational purposes at the Massachusetts Institute of Technology. The choice of this type of reactor was made after considering the inherent safety of various reactor types, the research program planned, and relative costs of various reactors.

The research program planned needs an available flux of about 10^{13} n/cm²/sec; this requires that the reactor operate at about 1 Mw.

Since the reactor is located adjacent to the campus, every consideration is given to safety features. The inherent safety of the heavy-water-moderated reactor due to its long thermal-neutron lifetime, together with the larger research volume available in this type of reactor, led to its being chosen despite its higher capital cost. To keep actual cost per useful experimental facility low, reactor design is as simple as possible, with no unnecessary frills.

The reactor, shown in Fig. 1, has many features found in other research reactors in the United States, as well as some original features. In particular, it has certain design features in common with the CP-5 reactor at Argonne National Laboratory and with the Omega West at Los Alamos. It bears the closest resemblance to CP-5, since both are heavy-water reactors of the same general type and use the same general type of fuel.

Unique Features

In some important respects, the MIT reactor differs from other reactors of its type. The most outstanding differences are in the core and reflector, the control system, and the layout and type of experimental facilities.

Core and reflector. As shown in Fig. 2, the MITR fuel element is an exact replica of the 18-plate MTR element, except that the two outside plates contain no fuel.

Within the 4-ft-dia core tank is a central fuel element, six elements arranged in a hexagonal pattern surrounding it, and finally 12 elements outside of that. These 19 elements make up the primary array to be used in most cases. Around the outside edge of the reactor tank are 11 additional fuel-element positions that can be used also. In essence, fuel elements in these positions act something like fission-plate converters and help improve the fast flux in selected ports. Thus, this arrangement provides a means of moving the highest flux region of the reactor. These positions also serve to provide sufficient fuel-loading latitude to insure that the reactor will go critical and operate properly, as well as to provide space into which small sample thimbles can be placed adjacent to the primary array.

Outside the core tank is a 2-ft-thick graphite reflector in a helium-filled envelope. Experimental ports penetrate the graphite region, but terminate just outside the core tank. There are no re-entrant thimbles in the tank, thus alleviating any thermal expansion problems.

Outside the graphite-reflector region is the steel and lead thermal shield, which consists of two 2-in. steel plates, and between them 1½ in. of lead, with appropriate cooling coils poured into the lead. The concrete biological shield is outside the thermal shield.

Control system. Six shim-safety rods and one fine-control rod are in the core tank. Their locations are chosen to minimize the shadowing of one control element by its neighbors, and the effects of the control elements on external experiments. The fine control element is near the edge of the D_2O tank.

Each control element consists of a hollow aluminum pipe containing cadmium. At the top of each of the aluminum pipes is a nickel-plated iron armature. To lift the control element out of the reactor core, an electromagnet is lowered from above until it makes

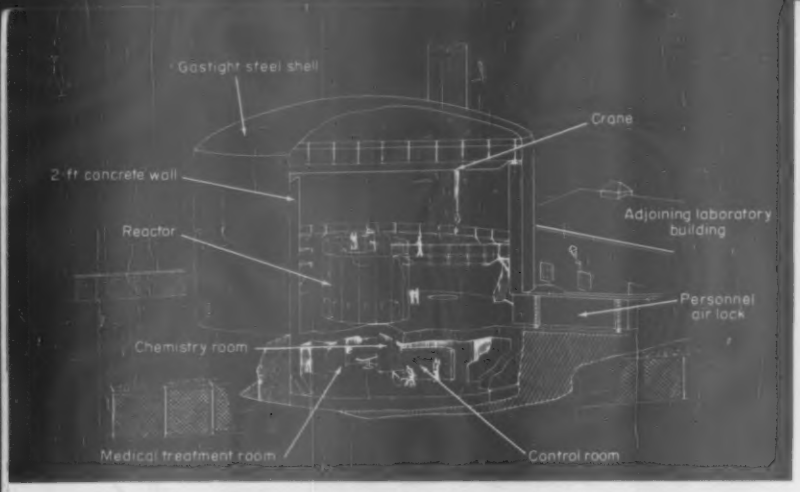

FIG. 4. Experimental area in MITR building is serviced by 20-ton crane on circular track. Concrete wall inside steel shell serves as shadow shield in unlikely event that substantial amounts of radioactive material escape into building. All entrances to building are of airlock type, with pressure seals on doors. Building automatically is completely sealed off if radioactivity is released

contact with this armature; the magnet current is turned on, and then the magnet is lifted upward and carries the control element with it. The "scram" action consists in breaking the current to the magnet, which causes the control element to drop downward under the force of gravity so that it returns into the core. Tests indicate that drop time is about 0.4 sec.

The entire control element is mounted in a single guide tube, which eliminates the possibility of misalignment. The whole unit is removable for repair or replacement and can be tested completely outside the reactor.

Calculations indicate that the reactivity worth of each of the six control elements is about 4.8%. Since no more than 7.8% excess reactivity will be allowed in the reactor at any one time, any two shim-safety elements are enough to shut down the reactor. The fine control element is worth about 0.5% reactivity.

Experimental Facilities

The MITR has a variety of ports and thimbles, as well as a thermal column and a medical-therapy facility.

Thermal column. As shown in Figs. 1 and 3, on one side of the reactor the graphite thermal column extends outward to within 30 in. of the reactor face. At the inner end of the thermal column is a 6-in. lead shutter, which can be operated remotely and normally will be used to cut off the gamma rays from the thermal column during shutdown periods so that the thermal column may be opened.

The thermal column is penetrated by three large ports in the front, by a port from the top, and by two ports, one of which comes in from either side. The thermal-column door can be pulled out on tracks across the reactor room floor, in such a way that an irradiation cave can be made at the outer end of the thermal column if desired.

Ports and thimbles. A horizontal section through the ports is shown in Fig. 3. There are six 4-in. ports, six 6-in. ports, one 12-in. port, one 6-in. through port, two 4-in. through ports, and four 4-in. instrument ports. Not shown in Fig. 3 are six vertical thimbles into the graphite region from the top of the reactor, and up to ten small-sample thimbles that can be inserted in the supplementary fuel-element positions at the edge of the core.

Fig. 1 shows a typical port, which happens to be 12-in. in diameter; it and the 6-in. ports have internal shutters of the general type indicated. These shutters operate vertically and are controlled by mechanisms accessible from above. The outer end of each port terminates in a box, which can be used for piping utilities into the reactor port for experimental purposes. These boxes also serve as a second step in the shield.

Medical-therapy facility. A large port underneath the reactor can be used to direct a neutron beam downward into a medical facility. It is hoped that a thermal neutron flux of 10^{10} n/cm²/sec can be achieved at the ceiling opening of this room. This thermal-neutron beam should be accompanied by a fast-neutron background held to 10^{7}/cm²/sec and a gamma background of 100 r/hr. Extensive use of the facility is planned by several medical research teams in the Boston area.

At the bottom of the heavy-water tank, several layers of bismuth are provided within the heavy-water tank as gamma shielding for the core. The layers are canned in aluminum.

The shutter mechanism used to shut off the medical port consists of an H_2O tank beneath the reactor tank, which when filled, serves to moderate and absorb the large part of the neutrons. Beneath this H_2O tank is a boron-containing shield and additional shielding for the gamma rays. When the facility is turned on, the H_2O in the water tank is removed, and then a movable sliding shutter is pushed to one side, removing the boron from the path of the beam, but allowing sufficient bismuth to remain in the beam path to reduce the gamma intensity to an acceptable level.

Other facilities in basement. In addition to the medical-therapy room, the basement includes: a gamma-irradiation facility (water-filled steel tank in which spent fuel elements are stored), chemistry hot labs, reactor control room, and equipment room for servicing the reactor and building. Figure 4 shows the arrangement of some of these facilities.

Time Schedule

The design of the reactor, up to the construction-drawing stage, was completed at MIT in November, 1955, and sent out for bid. ACF Industries of New York City was selected to complete the working design and to construct the reactor and building. ACF in turn selected J. Fruchtbaum as architect-engineer for the building, and J. W. Cowper as the building contractor.

The Atomic Energy Commission issued a construction permit on May 7, 1956. Ground was broken on the site at 138 Albany St., Cambridge, Mass., on June 6. The building foundations have been poured. It is expected that the reactor will be in operation by October, 1957.

Operating plans. Initially it is planned to operate the reactor on a 24-hr basis Monday through Friday, with weekend shutdowns. The first shift on Monday morning will be devoted to safety checkouts and to refueling. It is anticipated that one fuel element will be removed and replaced about once every four weeks after the reactor is in normal operation.

First reports on

Instability in SPERT-I

By S. G. FORBES, F. SCHROEDER, and W. E. NYER
Atomic Energy Division, Phillips Petroleum Company, Idaho Falls, Idaho

SEVERE INSTABILITIES have been found in the SPERT-I reactor (*1*). This instability was manifested by a series of diverging power oscillations, i.e., a series of pulses whose amplitude continued to increase throughout the period of observation. The results of this and subsequent tests are felt to be of sufficient interest to warrant their distribution in an extremely preliminary form. A more detailed investigation of this phenomenon is currently in progress and the results will be published at a later date.

The SPERT-I reactor is a light-water-moderated and -reflected reactor using enriched fuel in MTR-type assemblies. The core is immersed in a open vessel 4 ft in diameter and 10 ft high. The reactor and associated equipment have been described previously (*2*, 3).

First Instance

The instability was first observed when an attempt was made to insert 2% excess reactivity at a (linear) rate of approximately 0.08%/sec into the reactor with the water initially at boiling temperature. The ramp (linear addition of reactivity) was begun with the reactor critical at a power level of 100 kw at which point approximately 0.15% excess k was compensated by steam. As the rods were withdrawn the power rose more or less uniformly until about 1.6% additional reactivity had been added. At this point diverging oscillations appeared and the reactor was scrammed manually when the added reactivity reached 1.95%. The total reactivity added to the system in excess of the low-power critical condition was then 2.1%.

Examination of the oscillograph record revealed that while the initial power peak was less than 200 kw, the last power surge (Fig. 1) reached a peak of about 700 Mw and exhibited a minimum period of less than 10 msec. The power in this burst rose more rapidly than an exponential and a rough analysis indicated that reactivity was increasing at a rate of the order of 10%/sec during the burst.

"Terminated-Ramp" Tests

As a result of the foregoing observations the procedure was changed so that the ramp addition of reactivity was terminated at a preselected reactivity addition, but the reactor was allowed to run for an additional few minutes unless scrammed manually in the interest of safety. It should be emphasized that in tests of this type (referred to as "terminated ramps") the region of interest is the behavior of the reactor after the reactivity addition is complete. There is of course a transient power burst of about 5-Mw peak that occurs during the ramp addition. The character of this initial burst is determined by the

Doing This . . . **Caused This . . .**

ADDING 1.9% EXCESS reactivity in "unterminated ramp" from boiling critical at 100 kw with 2 ft of water above core top

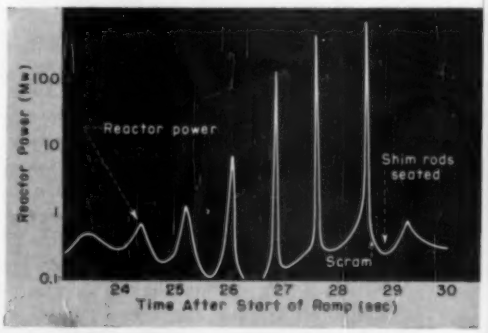

FIG. 1

ADDING 1.8% EXCESS reactivity in terminated ramp from boiling critical at 5 w with 2-ft head

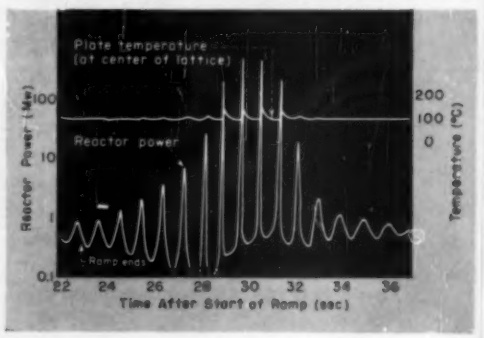

FIG. 2

initial power level and the rate of reactivity addition (*3*), but is not dependent on the total reactivity addition since it occurs early in the ramp. The instability referred to in this discussion occurs after the power transients associated with the reactivity insertion have disappeared.

Boiling tests. In a first series all tests were started from boiling at the 5-w level and the ramp rate was approximately 0.08%/sec. The total reactivity addition was 1% in the first test and was increased in 0.25% increments in subsequent tests until a total addition of 1.75% was reached. In tests having total reactivity addition of 1.5% or less the reactor behavior was essentially stable although minor fluctuations having the characteristic frequency observed in the unstable situation began to appear.

When the reactivity addition was 1.75% the reactor power fluctuations took on the character of oscillations that increased in amplitude until a considerable quantity of water was ejected from the tank. Thereafter, the oscillations converged and the power approached a steady value with only minor fluctuations (Fig. 2). The largest power surge exhibited a minimum period of ~15 msec. It was found that the water head above the core had been reduced to 1 ft from the initial value of 2 ft. This suggested that the stability was strongly dependent on hydrodynamics since such a change in top reflector thickness does not affect reactivity of the system. To check this point the water head was increased to 4 ft above the core and the rod withdrawal adjusted for a total reactivity addition of 1.5% since a similar test at 2-ft head had exhibited stable behavior (Fig. 3). The increased head resulted in diverging oscillations (Fig. 4), and the reactor was scrammed to avoid damage.

Room-temperature tests. Following the boiling tests the stability of the reactor at room temperature was investigated. Tests were made in which the total added reactivity was 1%, 1.5%, 2%, 2.25%, and finally 2.5%. All but the last run exhibited stable behavior with only mild oscillations of a nondivergent nature. In each case the power surge that occurs during the ramp addition of reactivity reached a peak of 19 Mw with a minimum period of approximately 90 msec. The 2.5% test ran for approximately 40 sec in a stable manner and then the oscillations began to diverge (Fig. 5). The rate of divergence was moderate (Fig. 6) giving ample time for observation before a scram became necessary. The final power peak (prior to the one during which the scram occurred) exhibited a minimum period of ~26 msec.

Status of Tests

Due to the preliminary nature of these tests many questions regarding details and reproducibility remain. However, the existence of severe instability in the SPERT-I reactor is certainly established. Visual observations and the motion picture records of the reactor behavior substantiate the general features of the power behavior as indicated by the ion chambers. Although the calibration of the external neutron detector in terms of power is open to question under conditions that may involve large void volumes in the core, nevertheless correlations with other manifestations of power behavior such as gamma flux, plate temperature rise, apparent period, transient pressure and total energy release show that the indicated peak powers are probably within a factor of two or three of the

Most Recent SPERT Results

Test no.	*Initial bulk water temperature (°C)*	*Water head (ft above core top)*	*Total reactivity addition (%)*	*Time from start of ramp to scram (sec)*	*Remarks*
3064	Boiling	2	1.5	~130	Oscillations began to diverge immediately after the end of the ramp, reached approximately 150 Mw, and quickly damped out.
3068	Boiling	2	1.5	~130	Immediately after the end of the ramp oscillations began to diverge, reached ~250 Mw, quickly damped out.
3069	Boiling	4	1.5	~150	Oscillations began to diverge immediately after the end of the ramp, reached ~250 Mw, and quickly damped down to steady oscillations of ~600-kw peaks for ~40 sec, then diverged to ~100 Mw followed by stable oscillations of ~15 Mw peaks for ~60 sec. Oscillations appeared to be damping out just before scram.
3077	~25	2	2.75	~ 74	Oscillations began to diverge immediately after the end of the ramp, reached ~200 Mw, and damped down to steady oscillations of ~100-Mw peaks for remainder of run. This amounts to ~60 such bursts in a test of this length.
3079	Boiling	2	2.0	~175	Oscillations began to diverge immediately after the end of the ramp, reached ~700 Mw and quickly damped out for ~40 sec, then diverged again to ~80 Mw and quickly damped out for the remainder of the run.

true values. Quantitative uncertainties of this order in no way invalidate the conclusions which may be drawn from these incomplete experiments.

Conclusions

Under certain conditions the SPERT-I reactor becomes extremely unstable resulting in large power peaks having very short effective periods. One condition appears to be that 1.5% reactivity be held in voids for both the boiling and subcooled tests. The rate at which reactivity increases in the system under these conditions is large compared with the rate at which it was originally added to the system. That is, the reactor has an intrinsic mechanism for rapid injection of large amounts of reactivity. The possibility of similar mechanisms in other reactors should be seriously considered, especially in those cases where a large amount of excess k may be held in voids. The ability of the core to survive these tests stems in part from the fact that the more violent surges expel water permanently from the core, a condition which is not necessarily typical of many research reactors. Instability appears to be aggravated by operation near boiling and with a large head.

In many respects the power pulses resemble the phenomenon of chugging found in the BORAX experiments (4). The frequency in both cases is sufficiently low to permit corrective action between power bursts. It is unknown whether the relative stability of BORAX represents a real difference in reactor behavior or is due only to the differences in the experimental conditions. SPERT tests subsequent to those reported here indicate that other important factors are as yet undetermined.

The gross features of these tests are summarized in the figures. Also included are some qualitative observations from a second series of tests which are given in the table on p. 42.

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4. J. R. Dietrich. Experimental determinations of the self-regulation and safety of operating water-moderated reactors, Geneva Conference Paper 481, June 1955

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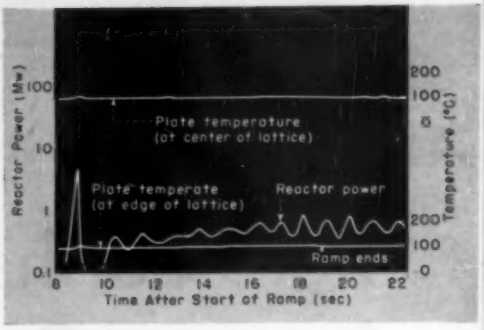
ADDING 1.5% EXCESS reactivity from boiling critical at 5 w with 2-ft head	
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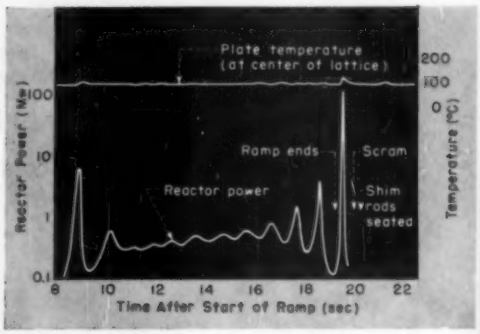
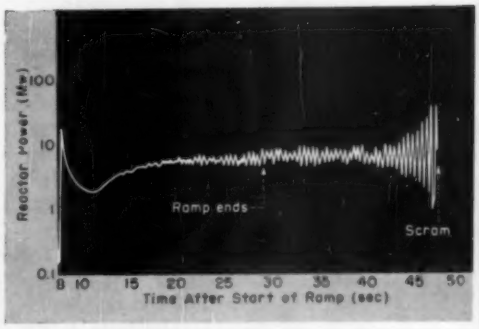
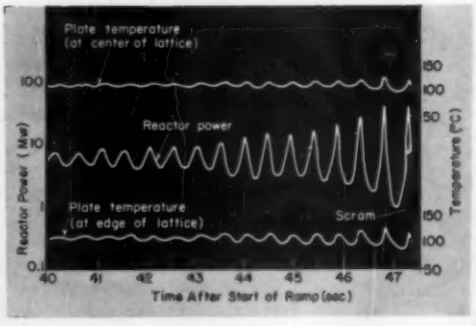
ADDING 1.5% EXCESS reactivity from boiling critical at 5 w with 4-ft head	
	FIG. 4
ADDING 2.5% EXCESS reactivity from room-temperature critical at 5 w with 2-ft head	
	FIG. 5
DIVERGENT PORTION of preceding test	
	FIG. 6

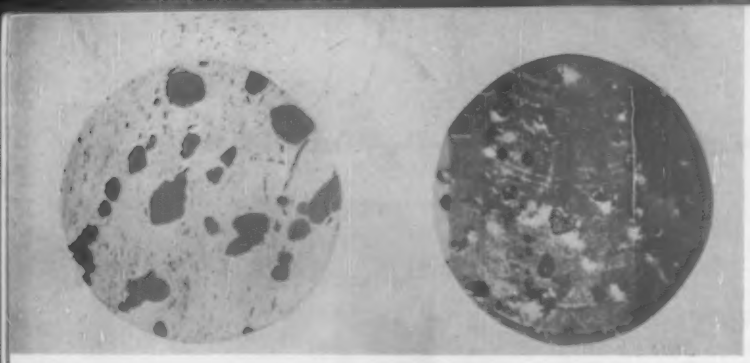


FIG. 1. Photomicrographs compare radiation damage in materials containing gadolinium (left) and boron (right). Absence of cracks, displacements, and "warts" is conspicuous in dispersion of 14 wt % Gd_2O_3 in titanium as compared with 1.2 wt % of B^{10} in titanium. Irradiation was to 10^{21} nvt

Rare Earths Show Promise as Reactor Control Materials

These misnamed elements are not scarce. They can be readily produced at costs that are not prohibitive. Europium oxide dispersed in stainless steel or titanium yields a control rod singularly free of radiation damage

By W. KERMIT ANDERSON
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OXIDES OF THE RARE EARTHS have good properties for reactor control materials. Good control elements can be made by using these oxides as the poison material and stainless steel or titanium as the matrix metal. In no real sense are the rare earths scarce. For this reason the term "lanthanon" has been introduced as a better term for them. Their prices are coming down fast, and their production can be guaranteed without extensive government financing.

From a nuclear standpoint, they offer large cross sections for n, γ reactions. Thus, as compared with boron-containing materials, solutions of the lanthanons in metals suffer little radiation damage. Of all of them, europium is the most interesting for our purposes. Each atom of its 47.8%-abundant isotope Eu^{151} will capture 5 neutrons before its usefulness as an absorber is completely dissipated.

Control Materials

Many materials with high thermal-neutron capture cross sections have been proposed for use as reactor-control materials. Boron, cadmium, hafnium, gold, silver, mercury, and several of the high-cross-section lanthanons have been frequently considered.

Boron, which has approximately a $1/v$ cross section is most desirable from a nuclear standpoint due to its relatively high cross section for epithermal neutrons. However, it captures neutrons by the n,α mechanism with production of lithium and helium. As a result all boron-carrying materials tested to date undergo such drastic irradiation damage that they offer little hope of being applicable for long-life, high-flux thermal reactors.

Hafnium has two distinct advantages. It is a poison that does not burn out, and it has a series of neutron-born daughters, each of which in turn reacts with neutrons by radiative capture (n,γ). It also has a number of resonances in the epithermal range that broaden the neutron spectrum over which it is effective. However, it is not generally available nor is it likely to become so in the near future. In addition it is heavy, and its thermal cross section is so low that essentially 100% hafnium in relatively thick slabs must be used to produce blackness to neutrons.

Mercury would have to be used as a liquid. It could be moved in and out of a core through suitable passages by pneumatic or hydraulic means, but a liquid system would not fail safe.

Cadmium, due to its low melting point and generally poor metallurgical properties, is poor. In addition, its cross-section cutoff at relatively low energies makes it a poor absorber.

Equal disadvantages present themselves for application of other common materials. Hence the reactor technologist must consider less available materials, including the lanthanons.

Advantages of Lanthanons

Advantages of the lanthanons as a class are apparent first to the metallurgist. He may reach complete frustration in attempts either to adopt unsuitable metallurgical materials to meet the physicist's requirements or to overcome the insurmountable difficulties of preparing boron-containing bodies. Most of the latter will not withstand the required neutron irradiation to 4–10% burnout of all atoms represented by the two-for-one $B^{10}(n,\alpha)Li^7$ reaction.

Nuclear properties of primary interest for four lanthanons that are potential control materials are shown in Table 1. Examination of these data leads us to eliminate dysprosium for

use in movable control elements because of its low cross section. It is still of some interest as burnable poison.

Samarium is high-cross-section material at low cost. It is available at present as the oxide at ~25¢/gm. However, examination of the isotope charts shows that Sm^{149} is the only high-cross-section isotope, and it occurs at low abundance. Hence samarium can be used only in short-lived systems. For high-power, long-lived cores it would be necessary to use concentrations not presently feasible from the metallurgical standpoint.

Gadolinium has two high-cross-section isotopes and falls in a range of intermediate interest. However, Gd^{156} has essentially zero absorption cross section and hence the element has no chain of neutron-capturing isotopes.

TABLE 1—Nuclear Properties of Some Lanthanons

Element or isotope	*Absorption cross section* (barns)*	*Percent abundance*	*Decay mode, half-life*	*Amt. required for blackness† (gm/cm²)*
$_{62}Sm$	5,500 ± 200			0.148
Sm^{149}	50,000 ± 20,000	13.8		
$_{63}Eu$	4,600 ± 400			0.177
Eu^{151}	9,000 ± 3,000	47.77		
Eu^{152}	5,500 ± 1,500		85% β^-, 13 yr	
Eu^{153}	420 ± 100	52.23		
Eu^{154}	1,500 ± 400		β^-, 16 yr	
Eu^{155}	14,000 ± 4,000		β^-, 1.7 yr	
$_{64}Gd$	46,000 ± 2,000			0.018
Gd^{155}	70,000 ± 20,000	14.73		
Gd^{156}	(very low)	20.47		
Gd^{157}	160,000 ± 60,000	15.68		
$_{66}Dy$	1,100 ± 150			0.741

* From BNL-325.
† As calculated from equation $N\sigma t = 2$ using a ¼-in. slab.

Superiority of Eu

With europium the reverse is true. Table 1 shows the series relationship developed by bombardment of Eu^{151} and its four neutron-born daughter isotopes. Each of these isotopes reacts with neutrons by the (n,γ) mechanism, and except for minor quantities of radioactive isotopes that decay by K-capture or β^- emission during core life, no changes in atomic number occur. Hence there is no great radiation damage of the type produced in B^{10}.

Table 2 is further illustration of the superiority of europium. This table displays crude estimates for the control requirements for a 100-Mw reactor with 2,000-hr full-power core life.

In the most elementary sense a control rod must be considered from two standpoints. First, it must have enough poison material to provide for burnout throughout the core life. Second, enough additional poison must be added to maintain blackness at the end of this lifetime. In this hypothetical design, blackness requirements are based on an arbitrary assumption that 50 ft² of ¼-in. slab will be used to control the reactor. The further assumption is then made that this slab will remain black so long as $\Sigma_a t \geq 2$. Here $\Sigma_a = N\sigma_a$ is the macroscopic absorption cross section for thermal neutrons, t is the thickness of the control slab in cm, N is the number of poison atoms per cm³ for the slab; and σ is the microscopic cross section in cm².

Burnout requirements are based on the assumptions that in regions of highest burnup, absorption will be twice the average for the slab, and that 20% of the neutrons produced will be absorbed by these slabs over the 2,000 hr of full-power operation.

These crude calculations, although not of quantitative significance in terms of a real reactor design, serve to estimate relative quantities of lanthanons required for reactor control. These numbers show the advantage of europium over the other usable lanthanons. The metallurgist's job is eased since less oxide is required. (Better properties can be obtained with lower concentrations for cermet dispersions.)

TABLE 2—Control Requirements for a Hypothetical 100-Mw Reactor

	Mass Required (kg)		
Lanthanon	*For blackness*	*For burnout*	*Total*
Sm	7	36	43
Gd	0.8	19	20
Eu	8	4	12

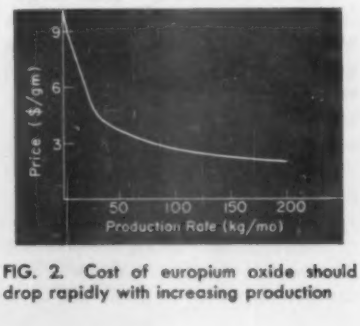

FIG. 2. Cost of europium oxide should drop rapidly with increasing production

Metallurgy of Eu

It is desirable to examine europium from the metallurgical standpoint. Gaining the metal at present would be costly and probably would require some development work. In addition, no knowledge of alloy systems exists and pure europium would have little or no corrosion resistance to coolants like water. It appears desirable to use it as the oxide since techniques are available for cermet dispersions.

Figure 1 compares the radiation damage in metal solutions of lanthanons and of boron. In addition to what the figure shows, boron-containing materials become brittle, swell, and crack.

Availability

The term "rare earth" is a misnomer, arising out of the desire of early chemists to create an ordered system by comparing these materials to the alkaline-earth family. Vickery (*1*) proposes the name "lanthanon" to replace "rare earth," as a name for elements between atomic numbers 57 and 71.

Europium, which is one of the scarcest of the lanthanons, is more plentiful than such "common" elements as silver, bismuth, antimony, and iodine.

Ores containing the lanthanons are numerous and widely dispersed throughout the earth.

Most significant sources in the U. S. are extensive monazite deposits in the

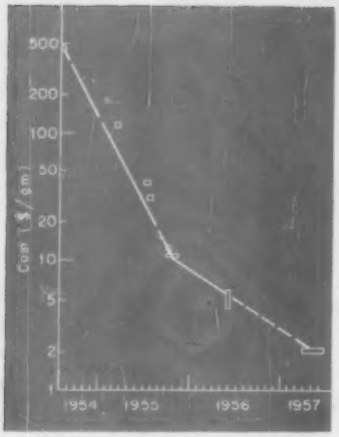

FIG. 3. Costs of europium oxide show this downward trend over last 2 years

southeastern states and in the Montana, Idaho, and Wyoming mountain regions. There is also an extensive thorite deposit in the latter region. Figures available from the U. S. Bureau of Mines indicate an estimated 1,230,000 lb of contained Eu_2O_3 in proven monazites in this country. Extensive unproven beds are also known, and in addition quite significant deposits of other ores are available. Gadolinium occurs in the monazites to 60–100 times the quantity of europium indicated above, and samarium would be present in about the same quantity. Hence the raw-material supply for all three would be adequate for any reasonably large-scale development.

During the past two years, the lanthanon industry has been rapidly developing not only in the United States but in other countries as well. One foreign supplier has a plant on standby capable of producing 99%-pure Eu_2O_3 at a rate of 25 kg/month. Several fairly large separations plants have been built in the United States, and more and larger plants are projected. All have been built or are proposed to be built with private capital. Most of them would be expected to use processes similar to that developed by Spedding's group at Iowa State College (*4*), although several of these operations do not involve ion exchange.

Since europium is of most interest among the lanthanons, it is well to point out that its separation is simpler than that of many of its sister elements due to the ease with which it can be reduced to the divalent state. Preliminary and independent cost estimates made by both the writer and Spedding (*5*) indicate that costs as low as $1.50/gm might be attained if moderately high production rates for Eu_2O_3 could be utilized along with some by-product utilization.

TABLE 3—Current Prices for Lanthanon Oxides

Oxide	*Price ($/gm)*	*Estimated quantities available* (kg)*
Gd_2O_3	0.90	10–100
Sm_2O_3	0.25	100–1,000
Eu_2O_3	5.00	10–100
Dy_2O_3	6.00	10–100

* These quantities are available on order with 2–4 months' delivery. In the case of Eu_2O_3 one supplier has 60 kg on the shelf with continuous production at 10 kg/month as of Dec. 1.

Cost Estimates

Current prices of lanthanon oxides range in the neighborhood shown in Table 3. These estimates are crude, particularly those on availability. None are shelf items as yet although several companies are advertising them for quick delivery.

These oxides are certainly available on the world market in good quality and reasonable quantity with short lead times for orders. The price quoted for Eu_2O_3 is tentative and is based on current estimates from reliable suppliers. Several kilograms have recently been purchased by various AEC installations at prices near $10/gm for Eu_2O_3 made after the order.

Cost trends. At least two competing suppliers have contributed "guesses" that indicate a probable cost trend as shown in the graph of Fig. 2. Production at higher rates would usually involve contracting for about one year of production at this rate.

Figure 3 shows price trends for Eu_2O_3 during the past two years. During this period, quantities of Eu_2O_3 available grew from a few miligrams in September, 1954, to nearly 5 kg/mo from one plant by January, 1956.

In summary, it can be stated that the developing lanthanon industry has ample raw materials and an expanding group of processing and manufacturing plants financed by private capital. The capacity is more than adequate for immediate demands for even the relatively scarce Eu_2O_3. By the time that demands for it could be affected by increasing manufacture of military and civilian reactors, it appears that an ample supply would be available.

As a final point in discussing costs of these materials, we can estimate costs of the 50 ft² of ¼-in. thick slab made from several different materials. The volume of this slab is ~30,000 cm³. The four rods compared are assumed to be formed of the four materials listed in Table 4 by the methods indicated. Shape of the final control rod would be complex, the cross section being cruciform or of some similar shape. The total number of rods can be assumed to be ~20. The total area of slabs formed into poison blades for all rods should be 50 ft², each blade being ¼-in. thick. Estimates of fabrication costs are based on AEC experience.

TABLE 4—Costs of Control Slabs

Material and fabrication method	*Cost* (thousands of dollars) Material*	*Fabrication*	*Total*
Welded hafnium slabs in complex shape	172	120	292
Welded boron steel slabs in complex shape	50	120	170
Complex extruded shape, AISI 304 steel powder with 12 kg Eu_2O_3 dispersed in steel	65	80	145
Same as above but titanium-boron at 2 wt. % B^{10}	50	80	130

* Cost basis: europium oxide, $5/gm; B^{10}, $10/gm; hafnium, $125/lb. Other common materials are at market prices.

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Computing 3-Group Constants for Neutron Diffusion

The 3-group method will predict reactivity and neutron flux distribution in homogeneous hydrogenous reactors with good accuracy. But one must determine the constants of the three coupled equations. Here is one way

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THE DEVELOPMENT of digital computers has permitted the solution of neutron age-diffusion equations for complex geometries in terms of a finite set of coupled partial differential equations. Each equation represents the neutrons in a specified energy interval, commonly known as an energy group. The behavior of neutrons within the group is determined by the group constants.

We present here a method for calculating three-group constants for U^{235}-loaded homogeneous hydrogenous reactors. Used with digital computing machines they permit accurate calculation of reactivity and flux distribution. The derivation is based on analysis of latest available nuclear-cross-section data and reactivity experiments. The method can be used to calculate constants for various compositions and will reliably predict reactor behavior for wide ranges of geometry. For a water-metal composition the reactivity is believed to be accurate to within 2%.

* Operated for the AEC by the General Electric Company.

How Many Groups?

The question naturally arises as to the optimal number of groups to attain the highest accuracy consistent with the cost of performing a problem on the machine. The cost is approximately proportional to the number of groups used. Increasing the number of groups does not necessarily increase accuracy as inaccuracies in the group constants may be aggravated. For a smaller number of groups, the errors in group constants may compensate over the wider energy range and be averaged

Symbols

D, diffusion coefficient
Σ, macroscopic cross section
σ, microscopic cross section
Σ_a, σ_a, absorption cross sections
Σ_s, σ_s, scattering cross sections
Σ_{sd}, σ_{sd}, slowing-down cross sections ($= \sigma_{in}/\xi\sigma_s$)
Σ_{in}, σ_{in}, inelastic scattering cross sections
Σ_f, σ_f, fission cross sections
Σ_{tr}, σ_{tr}, transport cross sections
$\Sigma_{1/v}$, $\sigma_{1/v}$, absorption cross sections for $1/v$ absorber
σ_U, total U^{235} absorption cross section
ν, number of neutrons produced per fission ($= 2.46$ for U^{235})
ξ, average change in ln E per collision
T, actual temperature of fuel-moderator region
T_{eff}, effective temperature for hardened spectrum
C, a function of $\Sigma_a/\xi\Sigma_s$
E, neutron energy
E_0, energy of thermal cutoff
γ, $\sigma_{1/v\,avg}/\sigma_{1/v}$ (see equation for $\sigma_{1/v\,avg}$)
ρ_i, density (gm/cm³)
M, U^{235} loading (gm)
V, volume (cm³)
τ, neutron Fermi age (cm²)
τ_2', Fermi age for second group to In resonance (1.44 ev)
u, lethargy ln (E_0/E). (E_0 arbitrarily chosen as 10 Mev)
S, rate of neutron production by fission (n/unit of lethargy)
v, ratio of amount of non-water material to amount of water in a medium
M, subscript for non-water material
x, y, average equivalence factors for transport and slowing-down effects in formula for neutron age
α, volume per cent

out. Thus one has the paradox, not uncommon in reactor design, of supposedly doing a calculation more accurately and arriving at a poorer result.

Another consideration in a comparison of few-group and many-group calculations, often overlooked, is ease of calculation and analysis of results. Input data for a small number of groups is relatively simple, and errors are easily located. Also it is possible to do hand calculations for simple geometries once the reflector savings are known. In contrast, many-group methods are cumbersome and formal. Errors are hard to find, and hand calculations are virtually impossible. Therefore, for most reactor calculations, especially of the survey type, the few-group method has the distinct advantage of speed and economy. However, with accurate input data, the many-group method is inherently more accurate and should be used when final reactor design is determined and precise results are needed.

At present we believe that three groups furnished sufficient accuracy to predict reactor operation. The constants for the three groups are derived from nuclear-cross-section measurements averaged over appropriate fluxes. Certain other constants are derived from the analysis of reactivity experiments. It is believed that these group constants will predict reactivity to within 2% for homogeneous water-moderated reactors of widely different geometries. In addition they will accurately describe flux and power distributions.

Group Boundaries

The three-group equations to be solved for each hydrogenous region in the reactor are

$$-D_1\nabla^2\phi_1 + \Sigma_{a11}\phi_1 = \nu(\Sigma_{f2}\phi_2 + \Sigma_{f3}\phi_3)$$
$$-D_2\nabla^2\phi_2 + (\Sigma_{a2} + \Sigma_{s12})\phi_2 = \Sigma_{s11}\phi_1$$
$$-D_3\nabla^2\phi_3 + \Sigma_{a3}\phi_3 = \Sigma_{s12}\phi_2$$

where the subscripts 1, 2, 3 designate the three groups. Other symbols are explained on p. 47.

The groups can be roughly designated fast, epithermal, and thermal. The first extends from 10 Mev to 180 kev or 0–4 in lethargy u (see table of symbols). The epithermal group extends from 180 kev to a thermal cutoff, determined by the composition of the medium. The lower bound of the first group is set so that essentially all neutrons born of fission are included in it.

The thermal group is defined as the energy region in which the neutron distribution is in equilibrium with the moderator atoms so that energy gains in collisions are as frequent as energy losses. On the other hand, in the epithermal group the neutrons always lose energy in collision.

TABLE 1—Equivalence Factors for Neutron-Age Determinations

	y_1	y_2	x_1	x_2
Al	0.103	0.006	0.922	0.195
Cr	0.176	0.014	1.47	0.862
Fe	0.186	0.021	1.20	1.39
Ni	0.224	0.041	1.62	2.82
Zr	0.107	0.005	1.33	0.547
C (1.6 gm/cm³)	0.115	0.046	0.986	0.618
Polystyrene $(CH)_n$(1.04 gm/cm³)	0.756	0.737	0.943	0.930
Polyethelene $(CH_2)_n$ (0.91 gm/cm³)	1.17	1.18	1.05	1.21
Furfuryl alcohol $(C_5O_2H_6)$ (1.13 gm/cm³)	0.664	0.640	0.943	0.850

THERMAL GROUP

In finding the constants for the thermal group—Σ_{f3}, D_3, and Σ_{a3}—we must deal with spectrum hardening and chemical-binding effects. Hardening results from preferential absorption of neutrons of lower energies.

Spectrum Hardening

In an absorbing medium the energy distribution of neutrons in the thermal range is different from that in a non-absorbing region. The physical explanation is that the slower neutrons have shorter life expectancies in a region of higher absorption. The more rapid disappearance of these neutrons with increased absorption causes an upward shift of the most probable neutron energy. This is commonly known as "spectrum hardening."

Calculation of the exact spectrum for hydrogenous moderators is further complicated by chemical-binding effects, which are extremely difficult to calculate, so that at present only calculations totally ignoring the chemical binding or including it in a rather crude manner have been attempted. Thus the true thermal spectrum has not been calculated and, although some experiments have been performed, they must be more fully interpreted before they will be useful.

We have adopted a simple thermal-hardening scheme. The method is to treat the flux as a shifted Maxwellian with most probable energy corresponding to a calculated T_{eff}. The prescription used, which is based on work of K. Cohen (*1*), is $T_{eff}/T = \left(1 + C\frac{\Sigma_a}{\xi\Sigma_s}\right)^2$. $\xi\Sigma_s$ is the macroscopic slowing-down cross section just above thermal and Σ_a is the monoenergetic absorption cross section at temperature T.

For hydrogen the microscopic $\xi\sigma_s$ is assumed to be constant and equal to 20 barns. For C, which is a function of $\Sigma_a/\xi\Sigma_s$, we use 0.75, which is based on the change of a $1/v$ cross section with $\Sigma_a/\xi\Sigma_s$ for a Wigner-Wilkins spectrum (*2*). Other work indicates similar formulas (*3, 4*).

The hardening calculated in this manner for no-rod–reactivity calculations is only a change in thermal base. For pure $1/v$ absorbers there is no effect on reactivity since the thermal utilization remains unchanged. For non-$1/v$ absorbers one would expect to observe some effect, but since the greatest deviation from $1/v$ for absorbers used

TABLE 2—Average Microscopic Transport Cross Sections for Fast and Epithermal Groups

	σ_{tr1}	σ_{tr2}
H_2O	6.03	16.44
Al	3.08	1.78
Cr	3.60	5.77
Fe	2.86	8.93
Ni	3.59	17.1
Zr	6.27	7.08
C	2.47	4.37
O	3.09	3.64
Polystyrene $(CH)_n$	3.94	10.77
Polyethelene $(CH_2)_n$	5.41	17.17
Furfuryl alcohol $(C_5O_2H_6)$	27.35	67.53

in reactors is small, the effect is small. Thus, the main effect of hardening is in the determination of control-rod effectiveness and water-gap peaking where the diffusion length and, consequently, the absolute values of the absorption and transport cross sections are involved.

Diffusion Coefficient

For the thermal group we take $D = 1/(3\Sigma_{tr\,avg})$. The difference between this and the more correct $[1/(3\Sigma_{tr})]_{avg}$ will be discussed with reference to the high-energy group for which it is of more consequence. To find D_3, therefore, we must compute $\Sigma_{tr\,avg}$.

The average transport cross section $\sigma_{tr\,avg}$ is defined as being

$$\sigma_{tr\,avg}(T_{eff}) = \sigma_{s\,avg}(T_{eff})\left[1 - \frac{2}{3A}\right] + \sigma_{1/v\,avg}(T_{eff})$$

For most moderating and structural materials, σ_s can be assumed constant in the thermal region so that $\sigma_{s\,avg}\left(1 - \frac{2}{3A}\right)$ is independent of actual temperature and spectrum hardening. However, the hydrogen transport cross section in the water molecule is affected by the chemical binding so that it is treated differently from the other elements. The hydrogen transport cross section in the water molecule has a $1/v$ dependence (*5*). The cross section used is normalized to a diffusion length of 2.73 cm at room temperature as measured by VanDardel and Sjöstrand (*6*); although Heintzé (7) measured a value of 2.86 cm in an exponential experiment. The microscopic hydrogen cross section at 2,200 m/sec corresponding to a 2.73-cm diffusion length is 37.14 barns, including absorption, and the average transport is averaged in the same manner as for a $1/v$ absorber.

The value of $\sigma_s\left(1 - \frac{2}{3A}\right)$ and $\sigma_{1/v}$ at a neutron velocity of 2,200 m/sec is shown below; $\sigma_s\left(1 - \frac{2}{3A}\right)$ is assumed independent of temperature and spectrum except for hydrogen for which it has a $1/v$ dependence, and the value listed for hydrogen is at 2,200 m/sec.

	$\sigma_s[1 - (2/3A)]$ (barns)	$\sigma_{1/v}$ (barns) at 2,200 m/sec
H	36.8(1/v)	0.33
C	4.5	0.0032
O	3.9	—
Al	1.4	0.230
Cr	3.8	2.9
Fe	11.4	2.53
Ni	17.4	4.6
Zr	6.2	0.18

Thermal Cutoff

The thermal cutoff is difficult to determine precisely. However, a simple expression is possible since by a neutron-conservation argument for the hardened spectrum, the energy E_c at which a $1/E$ spectrum joins the Maxwellian is given by

$$(E_c/T_{eff})^2 e^{-(E_c/T_{eff})} = \Sigma_a/\xi\Sigma_s$$

The thermal flux is proportional to $Ee^{-E/T_{eff}}$ so that the average thermal cross section is

$$\sigma_{avg}(T_{eff}) = \frac{\int_0^{E_c} \sigma(E) E e^{-E/T_{eff}} dE}{\int_0^{E_c} E e^{-E/T_{eff}} dE}$$

For a $1/v$ absorber

$$\sigma_{1/v\,avg}(T_{eff}) = \sigma_{1/v}(T_{eff}) \frac{\int_0^{E_c/T_{eff}} x^{1/2} e^{-x} dx}{1 - (E_c/T_{eff} + 1)e^{-E_c/T_{eff}}} = \gamma\sigma_{1/v}(T_{eff})$$

where γ approaches the usual $\sqrt{\pi}/2$ for $E_c \gg T_{eff}$, and $\int x^{1/2} e^{-x} dx$ is a tabulated function (*8*). For non-$1/v$ absorbers (U^{235}, Xe^{135}, Cd), a numerical integration is required.

For U^{235}, σ_f is measured to be $\sigma_U/1.184$ where σ_U is the absorption cross section.

By summing these quantities over the constituents of the medium we get the three constants that describe the behavior of the thermal group—D_3, Σ_{a3}, and Σ_{f3}.

Group 3 (Thermal)

$$\Sigma_{a3} = \Sigma_{U\,avg\,3}(T_{eff}) + \sum_{i=1}^{N} \alpha_i \Sigma_{1/v\,avg\,3i}(T_{eff})$$

$$\Sigma_{tr\,avg\,3} = \alpha_{H_2O}\Sigma_{tr\,avg\,H_2O}(T_{eff}) + \sum_{i=1}^{N-1} \alpha_i \Sigma_{tr\,avg\,3i}(T_{eff}) + \Sigma_{U\,avg\,3}(T_{eff})$$

$$D_3 = 1/(3\Sigma_{tr\,avg\,3})$$

$$\Sigma_{f3} = \Sigma_{U\,avg\,3}(T_{eff})/1.184$$

In these equations

$$\Sigma_{1/v\,avg\,3i}(T_{eff}) = 0.6(\rho_i/A_i)\sigma_{1/v\,avg\,3i}(T_{eff})$$

$$\Sigma_{U\,avg\,3}(T_{eff}) = 0.6\frac{M}{V} \times \frac{\sigma_{U3}(T_{eff})}{235}$$

HIGH-ENERGY GROUPS

We turn now to the energy summations over the fluxes of the fast and epithermal groups. The latter has a population nearly proportional to $1/E$ and can equally well be called the $1/E$ portion of the spectrum.

The lower limit of this group, the thermal cutoff, will vary from one reactor to another. Therefore in computing Fermi age we have adopted the procedure of summing to the indium resonance at 1.44 ev and computing an additional correction term to take account of the portion of the summation that is otherwise omitted.

Neutron Age

To find Σ_{s1} and Σ_{s2} we must find the neutron age, which is related to the distance traveled by a neutron from its birth to some lower energy. However, except for water, few direct age measurements have been performed. Therefore it is necessary to predict theoretically the ages that are to be used in reactor calculations.

The procedure that has been followed is to assume the experimental water age for a U^{235} fission-neutron source and consider the relative change of transport and slowing-down cross sections when other materials are added. For all cases the scattering is assumed to be isotropic in the center of mass system, and the cross sections are averaged over the fluxes to arrive at the average values. In this manner equivalence factors can be found for the other materials from the best cross-section data available. The resulting age determination should be fairly reliable.

By definition the Fermi age τ with a first-flight correction for hydrogen slowing down, is

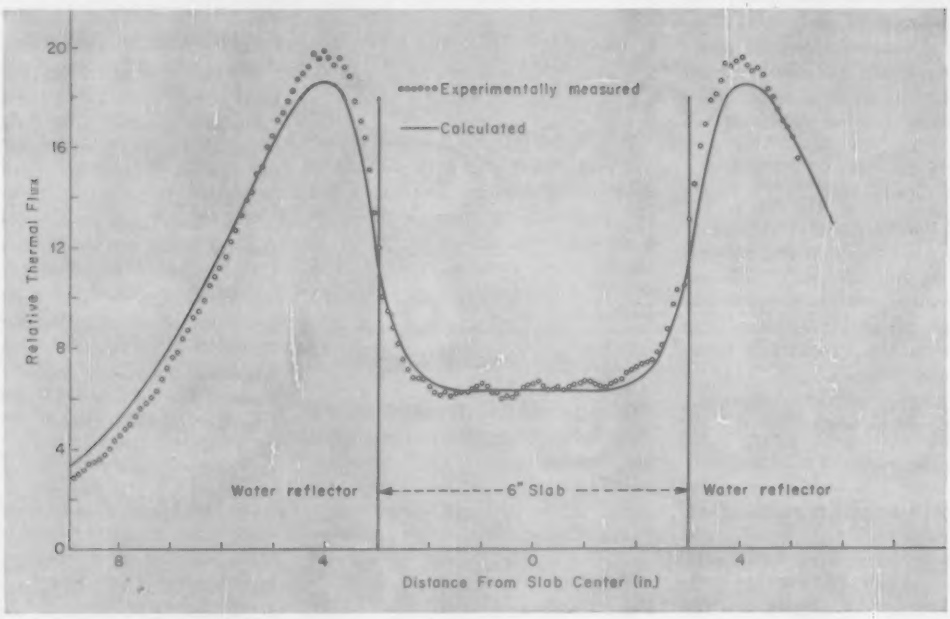
$$\tau(u) = \int_0^u \frac{\left\{\int_0^{u'} S(u'')du'' + S(u')\right\}}{3\xi\Sigma_s(u')\Sigma_{tr}(u')} du'$$

For water mixtures of metals or hydrocarbons, the resulting age can be expressed in terms of the water age as follows

$$\tau(u) = \tau_{H_2O}(u)(1+v)^2/(\rho_{H_2O} + vA_{H_2O}\rho_M\sigma_{si\,avg\,M}/A_M\sigma_{si\,avg\,H_2O})(\rho_{H_2O} + vA_{H_2O}\rho_M\sigma_{tr\,avg\,M}/A_M\sigma_{tr\,avg\,H_2O})$$

and consequently

Comparison with Experiment



Critical experiments were conducted in the SFR slab critical assembly at Bettis; the flux distribution was also measured. The composition of the core is

Constituent	Density (nuclei/barn-cm)
U^{235}	0.0001717
U^{238}	0.0000120
Zr	0.02132
H	0.03368
O	0.01233
C	0.005020

Three experiments, designated A, B, and C, have been analyzed. In all three cases the core composition remains fixed while the core thickness and width, as well as the reflector in the narrow core direction, varied. The reflector in the other two directions is water. For experiment A, the core dimensions are 6 x 30 x 40.5 in. with 20-in.-thick water reflectors. For experiment B, the core dimensions are 7 x 22 x 40.5 in. with a 1-in. water gap in the center of the core with 20-in.-thick water reflectors. Experiment C has a core 6 x 20.5 x 40.5 in. with a 6-in.-thick water-zirconium reflector and a metal-water ratio of unity.

A one-dimensional calculation was carried out using the Wanda[9] Code on the IBM 704. Reflector savings of 7.3 cm were assumed for the two large dimensions of the slab. The reactivity predicted for the three critical experiments (reactivity = 1) is as follows:

Experiment	Reactivity
A	0.992
B	0.995
C	1.007

The figure is a comparison of the measured thermal flux (points) with the calculated thermal flux (solid line) for experiment A normalized at the center of the core. There is good agreement in all cases.

[9] Wanda—the one-dimensional code.

$$\tau(u) = \frac{\tau_{H_2O}(u)(1+v)^2}{(\rho_{H_2O}+vy)(\rho_{H_2O}+vx)}$$

The cross-section averages are over the energy range of the flux.

If more than one material is present, the definition of age can be extended:

$$\tau(u) = \tau_{H_2O}(u)\left(1+\sum_{i=1}^{N} v_i\right)^2 \Big/ \left(\rho_{H_2O}+\sum_{i=1}^{N} v_i y_i\right)\left(\rho_{H_2O}+\sum_{i=1}^{N} v_i x_i\right)$$

Equivalence Factors

In order to average the cross section to find the equivalence factors, it is necessary to know the flux. For this purpose the flux can be separated into the two higher-energy regions. Since thermal cutoff varies from one reactor to another, the low energy used for the purposes of these calculations has been taken as the indium resonance at $u = 15.75$ ($E = 1.44$ ev). The method of extending the age to thermal energies will be described later.

In the fast region the flux is determined for the infinite medium by the Boltzmann equation, assuming that the inelastic spectrum of the metal is identical to the slowing-down spectrum of hydrogen. This latter assumption, while not strictly true, is a good approximation if a reasonable amount of water is present (>25%).

The average neutron age in water from a fission birth to the indium resonance has been calculated (*9*). However, a serious discrepancy exists between the calculated value, 25.3 cm², and the measured value, 30.9 cm² (*10*). Nevertheless it is believed that the calculated *relative* age values should be substantially correct when multiplied by 30.9/25.3. In this manner the average age to $u = 4$ has been found to be 24.0 cm².

Since the equivalence factors are best found by averaging over two different regions of the flux, the age is also

broken up in these two energy regions and two sets of equivalence factors are found. Thus

$$\tau_1 = 24\Big(1 + \sum_{i=1}^{N} v_i\Big)^2 \Big/ \Big(\rho_{H_2O} + \sum_{i=1}^{N} v_i y_{1i}\Big)\Big(\rho_{H_2O} + \sum_{i=1}^{N} v_i x_{1i}\Big)$$

$$\tau_2' = 6.9\Big(1 + \sum_{i=1}^{N} v_i\Big)^2 \Big/ \Big(\rho_{H_2O} + \sum_{i=1}^{N} v_i y_{2i}\Big)\Big(\rho_{H_2O} + \sum_{i=1}^{N} v_i x_{2i}\Big)$$

The total age to $u = 15.75$ is simply the sum of τ_1, and τ_2', and the determination of the equivalence factors determines the age.

The equivalence factors obtained in terms of H_2O are shown in Table 1. In the event a hydrocarbon is present without water v, x, y can be very simply redefined in terms of the hydrocarbon. There is good agreement using this method with a few experimental measurements on Al-H_2O and Zr-H_2O mixtures (*11*).

Total Age

All the previous ages have been calculated to the indium resonance. The additional age that must be added for multigroup calculation is a function of the thermal-cutoff energy. The increase in age in the region of the indium resonance is 0.44 cm² per lethargy unit. Thus increase in age to the thermal cutoff is

$$\Delta\tau = 0.44(u_c - 15.75)\Big(1 + \sum_i v_i\Big)^2 \Big/ \Big(\rho_{H_2O} + \sum_i v_i y_{2i}\Big)\Big(\rho_{H_2O} + \sum_i v_i x_{2i}\Big)$$

and the total age for the second group is the sum of τ_2' and $\Delta\tau$ and is

$$\tau_2 = [6.9 + 0.44(u_c - 15.75)]\Big(1 + \sum_i v_i\Big)^2 \Big/ \Big(\rho_{H_2O} + \sum_i v_i y_{2i}\Big)\Big(\rho_{H_2O} + \sum_i v_i x_{2i}\Big)$$

Diffusion Coefficients

As we have done for the thermal group, we compute D for the other two groups as $1/(3\Sigma_{tr\ avg})$. The difference between this and the more correct $[1/(3\Sigma_{tr})]_{avg}$ is negligible for the epithermal group since the microscopic cross sections are nearly constant over the entire group. It is not clear what the difference is for the fast group since the cross sections are energy dependent. For a 50% H_2O–50% Zr composition by volume the calculated difference is 3%, which is within the accuracy expected from calculation of the diffusion coefficient. However, the difference in the two methods of calculating the diffusion coefficient is small enough that the simplification of the calculation introduced by treating the transport cross section for each material separately is a decided advantage.

The average microscopic cross sections for the fast and epithermal groups are shown in Table 2. The total average transport cross section is considered to be the sum over all materials present, each weighted by its volume per cent; that is

$$\Sigma_{tr\ avg\ tot} = \sum_{i=1}^{N} \alpha_i \Sigma_{tr\ avg\ i}$$

The indices refer to individual materials, and the "avg" of each Σ represents the average for each material taken over the spectrum in each group.

Slowing Down and Capture

The slowing-down cross sections for the fast and epithermal groups are simply $\Sigma_{s1\,1} = D_1/\tau_1$ and $\Sigma_{s1\,2} = D_2/\tau_2$.

The average epithermal absorption for a $1/v$ absorber in a $1/E$ flux is

$$\sigma_{1/v\ avg\ 2} = \frac{\int_{E_c}^{180\ kev} \sigma_{1/v}(T_{eff})\sqrt{T_{eff}}\,dE/E^{3/2}}{\int_{E_c}^{180\ kev} dE/E} = \frac{2\sqrt{T_{eff}/E_c}}{u_c - 4}\,\sigma_{1/v\ 2}(T_{eff}) = 2\sqrt{T_{eff}/E_c}\,\sigma_{1/v\ avg\ 2}(T_{eff})/\gamma\,\Delta u$$

Here $\Delta u = u_c - 4$, u_c is the lethargy corresponding to E_c, and $\sigma_{1/v\ avg}(T_{eff})$ is the average thermal absorption cross section.

The resonance structure of U^{235} has only been measured up to about 40 ev. Also, even for highly enriched fuel (~90%), the U^{238} resonance capture is not negligible and is difficult to calculate exactly. Therefore the epithermal capture and fission of the fuel has been fitted by reactivity experiments. The values necessary to obtain criticality for zirconium-water and stainless-steel–water core compositions are

$$\sigma_{U\ avg\ 2} = 2(T_{eff}/E_c)^{1/2}\sigma_{U\ avg\ 2}/\gamma\Delta u$$

$$\sigma_{f\ avg\ 2} = \sigma_{U\ avg\ 2}/1.35.$$

Summing over the fast and epithermal groups we get the remaining coefficients required for our age-diffusion equations.

Group 1 (Fast)

$$\Sigma_{tr\ 1} = \sum_{i=1}^{N} \alpha_i \Sigma_{tr\ i}$$

$$D_1 = 1/(3\Sigma_{tr\ 1})$$

$$\Sigma_{a1\ 1} = D_1/\tau_1$$

Group 2 (Epithermal)

$$\Sigma_{tr\ 2} = \sum_{i=1}^{N} \alpha_i \Sigma_{tr\ 2i}$$

$$D_2 = 1/(3\Sigma_{tr\ 2})$$

$$\Sigma_{a1\ 2} = D_2/\tau_2$$

$$\Sigma_{a2} = 2(T_{eff}/E_c)^{1/2}\Sigma_{a2}/\gamma\Delta u$$

$$\Sigma_{f2} = \Sigma_{U2}/1.35 = 2(T_{eff}/E_c)^{1/2}\Sigma_{U2}/1.35\gamma\Delta u$$

General Observations

The three-group constants described here are *not* unique. There are a number of factors arbitrarily chosen such as method of averaging, method of hardening, the energy width of the groups, etc. Thus there are undoubtedly other combinations that would also give the correct answer—the correct answer being agreement with experiment in reactivity and distributions of power and flux.

This entire method can also be adapted to heterogeneous low-enrichment lattices. Fast fission, resonance-escape probability and thermal utilization can be incorporated in a new set of constants to give the proper k_∞ for the lattices. However, it would probably still be necessary to use reactivity experiments to completely evaluate the epithermal constants.

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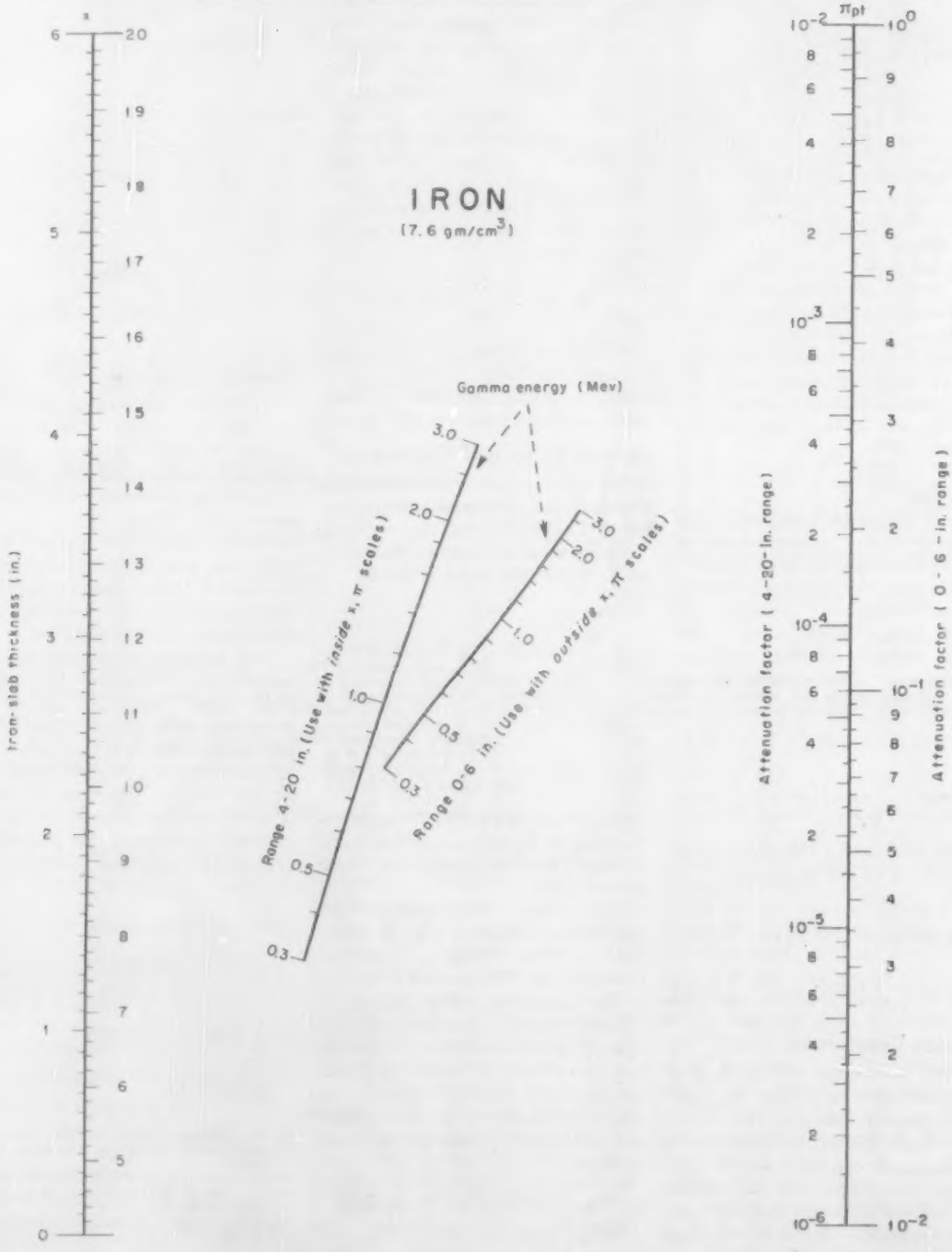
Shielding

Gamma Attenuation with Buildup in Lead and Iron

By DAVID G. CHAPPELL
Knolls Atomic Power Laboratory, General Electric Company, Schenectady, New York



THESE NOMOGRAMS give attenuation factors for lead and iron shielding slabs used with point sources of gamma radiation.

The nomograms include the effect of buildup—the scattering of degraded radiation into the beam from all points of the absorber. Absorption coefficients and buildup factors are from APEX 176.*

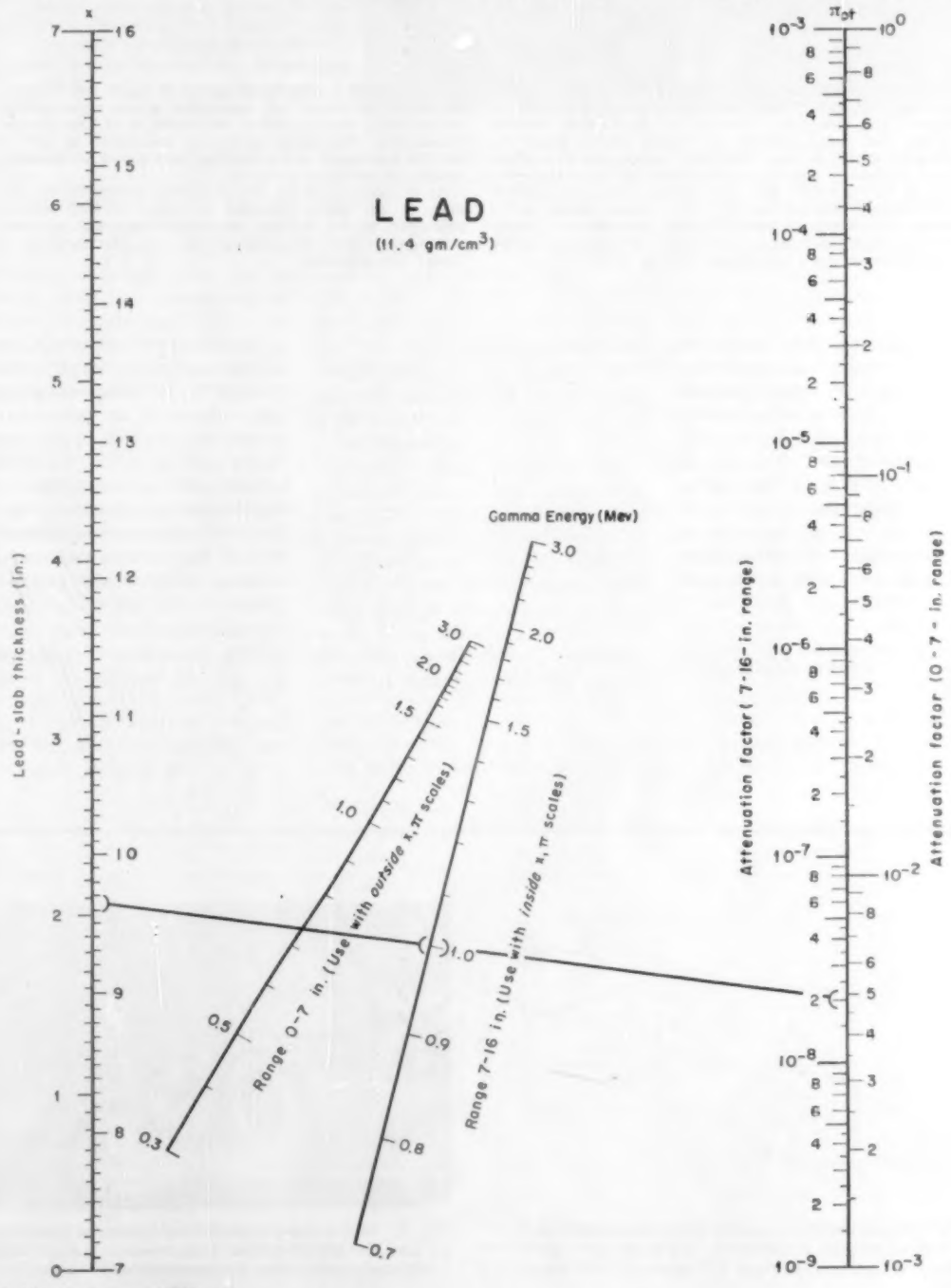
Over most of the range, accuracy is 10% or better. At extreme positions accuracy is better than 25%.

Example. How thick must a lead shield be to reduce the dose from a point source of 1.0-Mev gammas by a factor of 2×10^{-8}? We draw a line from the number 2×10^{-8} at the right through 1.0-Mev on the proper gamma-energy scale. Reading on the appropriate side of the slab-thickness scale we find the answer: 9.67 in.

* * *

I wish to acknowledge the assistance of Miss Joyce Berger, who drew the nomograms.

* Miscellaneous data for shielding calculations. Compiled by John Moteff. APEX 176 (1954).


LEAD
(11.4 gm/cm³)
Gamma Energy (Mev)
Lead - slab thickness (in.)
Range 0-7 in. (Use with outside x, π scales)
Range 7-16 in. (Use with inside x, π scales)
Attenuation factor (0 - 7 - in. range)
Attenuation factor (7-16- in. range)

Thyroid Uptake Measurements

By G. J. HINE, B. A. BURROWS and J. F. ROSS*
Radioisotope Service, Veterans Administration Hospital and Boston University School of Medicine, Boston, Massachusetts

A recent extensive survey of radioiodine thyroid-uptake measurements revealed a disturbingly wide spread in results obtained. The survey was conducted by the Medical Division of the Oak Ridge Institute of Nuclear Studies under the direction of M. Brucer. They sent mannequins with simulated thyroids containing "mock-iodine" (a long-lived mixture of Ba^{133} and Cs^{137} that emits gamma rays with a spectral distribution similar to that of I^{131}) to many clinical radioisotope laboratories in the U. S. and Great Britain. Those surveyed were asked to do an "uptake" measurement on the mannequins so that a comparison could be made.

The fact that a considerable spread of results was obtained in this survey means that radioiodine uptake measurements are not being made as well as they could be; at least in some laboratories. This seems particularly unfortunate in light of the fact that use of radioiodine has been one of the principal benefits of the isotope program.

At the request of the editors of NUCLEONICS the authors of this article expanded the scope of their original paper—on the use of plastic scintillators for uptake measurements—to include discussion of the principles involved in uptake measurements.

WITHIN the last ten years, the thyroid uptake of I^{131} has become a standard clinical procedure (*1*) in many hospitals using one of a number of commercial instruments available for external measurement of I^{131}. Though the actual test is simple to perform, the accuracy of the results depends on the technique used. Insufficient emphasis on standardization and reproducibility of distances used causes errors up to 50–100%.

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The Measurement

To estimate radioiodine uptake as percentage of the administered dose, one must compare the I^{131} activity of the dose with that distributed in the patient's thyroid gland. The first measurement can be made on an aliquot of the dose, prepared either as a dry source or as a liquid source of 1–100-ml volume. The source for the other measurement is the I^{131} distributed in the patient's thyroid gland. The weight of thyroid glands varies considerably (~20–150 gm) and is frequently difficult to estimate in vivo.

The activity of each source does not depend solely on its I^{131} activity. Some of the I^{131} γ-rays are attenuated and scattered in the reference source as well as in the thyroid gland and the tissues surrounding it. In particular, a fraction of the γ-rays emitted from the thyroid in a direction away from the detector are backscattered so that some of the scattered γ-rays reach the detector (schematically illustrated in Fig. 1).

Finally, the actual counts depend not only on the number of γ-rays reaching the detector, but also on its count-

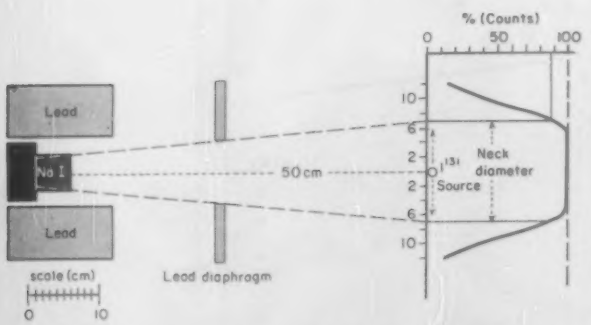

FIG. 2. Diagram of lead-shielded scintillation crystal and lead diaphragm used as collimator. Curve on right shows sensitivity of response to small I^{131} source 50 cm away

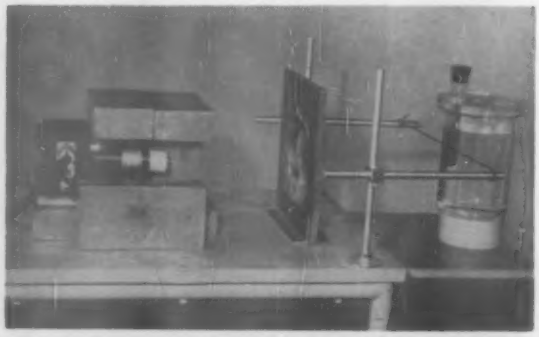

FIG. 3. Water phantom, positioning device and lead diaphragm as used for thyroid-uptake measurements. Lead shielding of scintillation counter cut for demonstration only

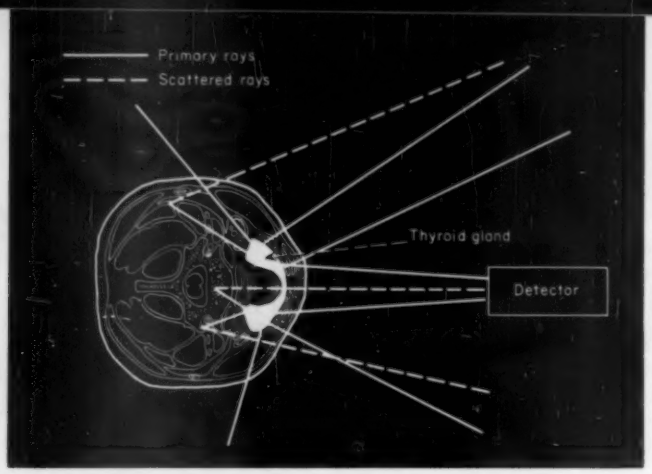

FIG. 1. Schematic cross section of human neck, including normal thyroid gland containing I^{131}. Primary γ-rays are shown emitted from thyroid as well as γ-rays scattered by surrounding tissues

ing efficiency for γ-rays of different energies.

In most instruments NaI crystals are now used as γ-ray detectors. Recently plastic phosphors suitable for scintillation counting have become available. We will evaluate the characteristics of both kinds of scintillation counters for I^{131}-uptake measurements after outlining the geometrical factors involved in all I^{131}-uptake measurements.

Geometrical Factors

Geometrical factors, collimation and positioning, are simple considerations but they are often neglected.

Gamma-ray collimation. At the time of the thyroid-uptake measurement a fraction of the administered I^{131} dose is in the patient's extrathyroidal tissues. If a γ-ray counter without collimator is positioned at some distance from the patient's neck it "sees" a large fraction of the whole body and a falsely high uptake value is obtained. Therefore, it is important to use a counter with good collimation so that only γ-rays from the neck region are counted.

Generally, the thyroid gland consists of an isthmus and two lobes, one on each side of the trachea, extending 4–5 cm on both sides of the midline of the neck (see Fig. 1). Therefore, a detector positioned at some distance from the patient's neck must have almost uniform sensitivity for γ-rays emitted from within a rather large volume with a diameter close to that of the patient's neck. This can be accomplished either with a conical "flat-field" collimator (*2*) or the proper size lead diaphragm (*3*) half-way between the patient's neck and a shielded scintillation counter with a wide opening towards the diaphragm (see Figs. 2 and 3).

If the collimation used is too narrow and does not have uniform sensitivity over the neck area, unreliable uptake values result. Frequently cylindrical lead collimators are employed which result in about twice the sensitivity for a source at the center axis as for a source six centimeters to the side.

Counting distance. There is a geometrical error because of variations in thyroid size and position and variations in thyroid-detector distances. For patient measurements the distance between the counter and the center of activity in the thyroid can not be accurately determined. Use of a counting distance of 50 cm reduces the resulting error in uptake measurements to a few percent.

The accurate *control* of the distance for each measurement is as important as the choice of counting distance. This requires a positioning device for patient and reference standard—a simple setup will suffice, see Fig. 3. The system employed may vary with the position of the patient, lying or sitting, but should be reproducible.

Energy Spectra

The second important consideration in making accurate uptake measurements is insuring that the detector responds equivalently to I^{131} whether it

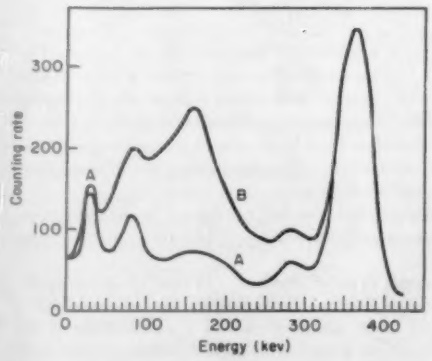

FIG. 4. Pulse spectra of I^{131} γ-rays. Curve A: Point source in air. Curve B: 50-ml source inside 2,000-ml beaker filled with water

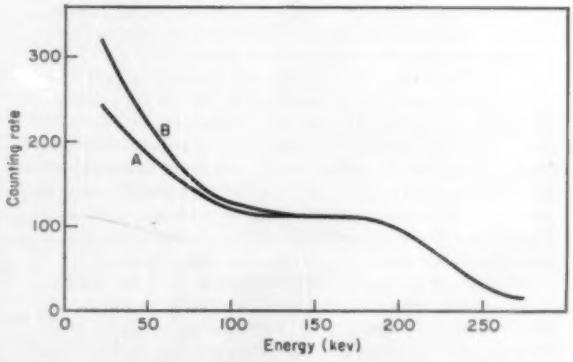

FIG. 5. Pulse energy spectra of I^{131} γ-rays measured with plastic scintillator. Curve A: 50 ml source in air. Curve B: 50 ml source in water phantom

is in the standard or in the patient's thyroid.

I^{131} spectrum. The energies of the I^{131} γ-rays and the number of each per disintegration (*4*) are given in the table. Note that the number of 364-kev γ-rays is almost ten times greater than any of the others. Curve A of Fig. 4 shows the corresponding γ-ray spectrum for an I^{131} *point* source obtained with a 1¾-in.-dia × 2-in.-long NaI(Tl) crystal (*5*). The relative height of the peaks depends on the crystal size and geometry as well as on the photoelectric absorption of the γ-ray lines of different energy and intensity (*6*). The two γ-ray lines with energies above 364 kev are disregarded in the present discussion though they do contribute a few percent to the total counting rate.

Degraded spectrum. In passing through tissue or water the I^{131} γ-rays are attenuated mainly by the Compton interaction. When a primary γ-ray is absorbed, a secondary electron is produced together with a secondary γ-ray. Since the secondary γ goes in a direction different from the primary, the secondary γ-ray is frequently called the "scattered" γ-ray. As the primary γ-ray transfers some of its energy to the secondary electron, the energy of the scattered γ-ray is always less than that of the primary one. In Compton absorption the total number of γ-rays is not altered but their energy is reduced. This is often called "degradation" of the attenuated γ-ray beam.

To show the effect of such degradation, the energy spectrum of the γ-rays

I^{131} Gamma Rays

γ-ray energies (kev)	*No. of γ-rays per disintegration**
80	0.06
284	0.06
364	0.81
637	0.09
722	0.03

* The I^{131} disintegration scheme is still not completely established.

that escape from an *extended* source embedded in a scattering medium is shown in curve B of Fig. 4. The source here is a 50-ml I^{131} solution placed inside a 2,000-ml beaker filled with water (Fig. 3). The difference between the two curves of Fig. 4 (the two curves have been normalized to give equal intensity for the 364-kev lines) is striking and can be reflected in considerable differences in counting rate for the same activity in standard and thyroid if the counting arrangement is not properly designed.

Three methods using NaI are discussed in the box below; the method we use will be described in the section after the next.

Use of Phantom

The detailed considerations leading to a choice of containers for the I^{131} standard solution and the water phantom and their sizes and shapes cannot be discussed here in detail. As a matter of fact the conditions can be varied considerably without affecting the counting rate appreciably. Furthermore, in no case can the absorption and scattering conditions be reproduced accurately for each individual patient.

Phantom design. A water phantom which has given satisfactory results, when used with the collimating diaphragm and the 50-cm source distance mentioned above, is shown in Fig. 3. A 100-ml Lusteroid test tube filled with a 50-ml I^{131} solution is submerged in a 2,000-ml glass beaker filled with water. The Lusteroid tube is positioned through a Lucite top plate so that there is a 1-cm-thick layer of water between the test tube and the part of the glass beaker facing the counter. In height, the I^{131} solution is positioned at the center of the 15-cm-high beaker.

By extending the height of the water phantom, neither the spectrum nor the counting rate is altered, since the lead diaphragm limits the volume from which scattered γ-rays can reach the scintillation counter to about the size of the 2,000-ml beaker.

Phantom and patient spectra. Figure 7 shows the pulse energy spectra obtained with the 50-ml I^{131} source in the water phantom under the conditions shown in Fig. 3 (solid line) and with a patient with I^{131} in his thyroid placed at the position of the water phantom (dashed line). Both spectra agree well in both the high- and low-energy components. When the 2,000-ml water phantom is replaced by a 600-ml beaker filled with water, the

Uptake Measurement with NaI

The following three methods, properly used, can give satisfactory iodine uptake data.

NaI with pulse height discrimination. *From the two I^{131} spectra shown in Fig. 4 it is obvious that there would be no appreciable difference between the γ-ray spectrum from a point source and from a volume source in a scattering medium, if only those pulses corresponding to an energy above 300 kev were counted. For such energy discrimination NaI crystals are used as detectors. If a single integral discriminator is employed to eliminate the low-energy pulses, it has to be adjusted at that energy level where the counting rate remains constant when the I^{131} source is positioned in contact with a scattering medium. The other possibility is to use a γ-ray spectrometer adjusted to the 364-kev line (2); then pulses above the line are also eliminated.*

When either one of these two methods is used, the observed counting rates are not affected by the amount of scattered radiation reaching the scintillator. The resulting reduction of the counting rates by a factor of more than two has a certain disadvantage, especially when the I^{131} activity is low. Also neither method solves the problem of γ-ray absorption in the patient's thyroid and the overlying tissues, which depends on the weight of the gland and its location in the neck of the patient.

Use of Lead Filters. *Since γ-ray absorption in lead increases very rapidly with decreasing γ-ray energy and since the energy of the back-scattered I^{131} γ-rays is about half that of the primary 364-kev γ-rays, a 1/16-in.-thick lead filter can be employed to eliminate most of the scattered γ-rays. Such a filter placed between the γ-ray detector and source reduces the number of primary 364-kev γ-rays which are detected to 63%, while the number of backscattered γ-rays is reduced to about 3%, of their unfiltered abundance (7). This results in a loss of more than 50% in counting sensitivity.*

The lead filter method also does not correct for the absorption of primary γ-rays in the volume source and tissues surrounding the thyroid.

Reference source in water phantom. *Instead of excluding the scattered radiation from the measurements, the reference source can be counted under conditions which simulate those of the thyroid in the patient's neck (7). This increases the counting rate and, in addition, the absorption of the I^{131} γ-rays can be reproduced approximately. There are many designs for thyroid-neck phantoms (7–10); ours is discussed above.*

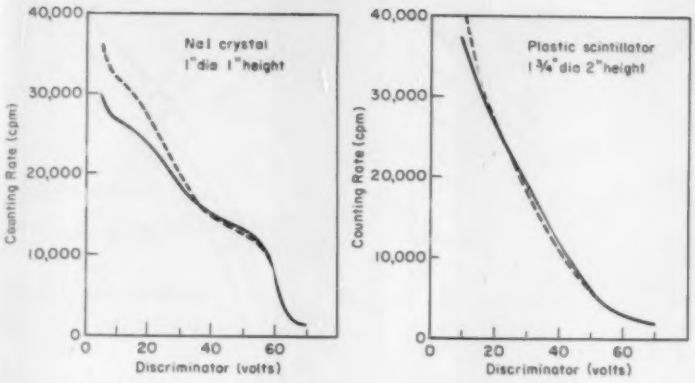

FIG. 6. Integral discriminator curves for 50-ml I^{131} source in air (solid curves) and in water phantom (dashed curves) as measured with NaI(Tl) crystal and plastic phosphor

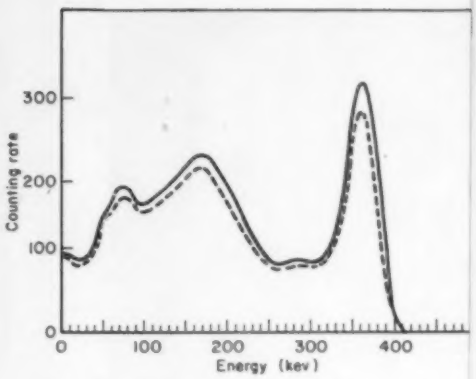

FIG. 7. Pulse spectra; 50-ml I^{131} reference source in water phantom (solid line) and dose in patient's thyroid (dashed)

agreement of the two spectra (phantom and patient) is less satisfactory.

Finally, the use of the water phantom not only corrects for absorption and scattering, but also for losses of γ-rays emitted from various areas of a volume source due to differences in distance. For a counting distance of 50 cm this is only a minor correction and therefore the exact dimensions of reference source and phantom are again not decisive.

The measurement of the reference standard in a phantom has certain advantages. It simplifies the accurate positioning of the source and, depending on the counting method, simulates the γ-ray absorption, scattering, and geometrical losses observed in patients.

UPTAKE MEASUREMENTS WITH PLASTIC PHOSPHORS

Plastic phosphors, being low-atomic-number materials, absorb energy from γ-rays by the Compton effect alone. As a consequence the characteristic photoelectric lines of the NaI(Tl) spectrum are missing in the pulse spectrum obtained with a plastic scintillator (curve A of Fig. 5). The minor contribution of the scattered γ-rays, when the source is placed in a water phantom (curve B of Fig. 5), shows up in the lower energy part of the spectrum. From these curves it is obvious that the use of a plastic scintillator precludes the need for a γ-ray spectrometer.

Effect of scatter decreased. If the NaI crystal is replaced by a plastic phosphor* the scattered γ-rays contribute to the total counting rate to a lesser extent. In Fig. 6 the integral discriminator curves for both a NaI crystal and a plastic phosphor are shown. For each of them, a 50-ml I^{131} source is used, once in air and then in a water phantom. While the increase in *total* counting rate is about 20% for the NaI(Tl) crystal, it is only about 10% for the plastic phosphor. Furthermore, if the I^{131} uptake measurements are performed at such a discriminator setting that the contribution of the scattered γ-rays has been eliminated, more than 50% of the NaI(Tl) counts are lost while the counting rate with the plastic phosphor is reduced by only 25%.

Relative counting rate. Due to the absence of photoelectric absorption in the plastic phosphor and its low mass density of one compared with 3.67 for NaI, the γ-ray absorption of the plastic is much lower than that of NaI of equal volume. Therefore, the counting rates from a NaI(Tl) crystal are much higher than from a plastic scintillator of equal size.

However, because of cost, the size of the NaI(Tl) crystal used for thyroid-uptake measurements is usually limited to 1-in. dia and 1-in. height. A (less expensive) plastic scintillator of 1¾-in. dia and 2-in. height can be mounted on the standard 2-in. photomultiplier tube. The efficiency of this 2-in. plastic scintillator for I^{131} counting is slightly higher than that of the 1-in. NaI crystal, even if the backscattered radiation is included in the counting rate of the latter (Fig. 6).

Furthermore, while the plastic phosphor is very stable and unbreakable, the NaI crystal is fragile and has to be kept in an air-tight container because of its highly hygroscopic property.

Results with Plastic Phosphor

Reproducible and accurate results for I^{131} uptake have been obtained with a 2-in. plastic phosphor in this laboratory during the last two years. A series of 33 patients were measured with a 1-in. NaI(Tl) crystal and the 2-in. plastic phosphor. The reference standard was placed in the water phantom as shown in Fig. 3. Only a single 24-hour uptake was performed. In 27 cases the values obtained with the two systems were in quite good agreement (within 4%) while for 6 cases the two values differed by 4–10%. However, no systematic difference between the two systems could be observed.

* * *

The assistance of L. A. Sarkes and J. A. Cardarelli in performing the measurements is gratefully acknowledged.

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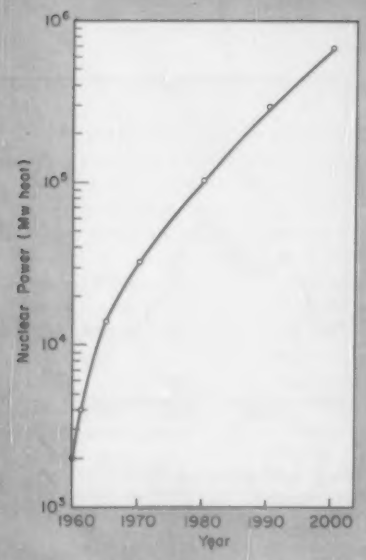

FIG. 1. Predicted U. S. nuclear power (heat) generation, assuming 8-fold increase by 2000, and half of plants built in 2000 are nuclear

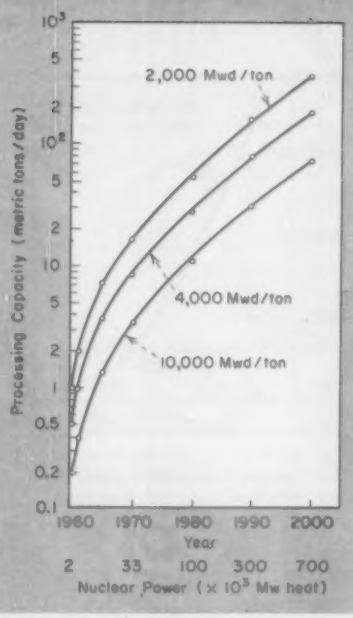

FIG. 2. Radiochemical-processing-capacity requirements. Average irradiation level (Mwd/ton) of spent reactor fuel is taken as parameter

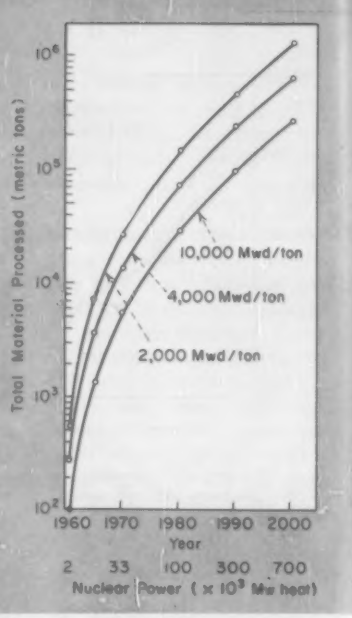

FIG. 3. Predicted total spent fuel processed. Average irradiation level of spent fuel (Mwd/ton) is taken as parameter

Economics of Waste Disposal

By the year 2000, accumulated fission-product activity may be greater than 3×10^{11} curies. To dispose of it, the authors estimate a cost of $1.60–$64/gal will be permissible for the predicted nuclear-power economy

By H. R. ZEITLIN,* E. D. ARNOLD, and J. W. ULLMANN
Chemical Technology Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

IN A NUCLEAR-POWER ECONOMY, the cost of disposing of reactor fission-product waste will be significant. To determine the magnitude of the waste-disposal problem and to define the limits within which the solution must be found, we have studied three aspects:

1. How much waste will accumulate by the year 2000?
2. What fraction of the cost of nuclear power can be economically allocated to waste disposal?
3. What are the optimum waste-storage (cooling) period and shipment weight (including shield) for minimum cost?

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Predicted Accumulated Activity

Based on a predicted nuclear power economy growth rate, calculations have been made to determine as a function of time the magnitude of several quantities important to the radiochemical-processing and waste-disposal industries. Included are such quantities as required processing capacity, buildup of activity of important fission products, and accumulated volume of high-activity liquid wastes.

If it is assumed that the installed electrical plant capacity of the United States will increase eight-fold during the next 50 years (*1*, *2*), that there will be 500 Mw of installed nuclear electric capacity in 1960, and that half of all new plants built in the year 2000 will be nuclear plants, the installed nuclear plant capacity, N (Mw), at time T (years after 1960) will be

$$N = 5{,}800(1.09^T - 1) + 500$$

Assuming a thermal efficiency for the reactor system of 25%, the heat power requirements will be four times as great

$$N(\text{Mw heat}) = 23{,}200(1.09^T - 1) + 2{,}000$$

This equation is plotted in Fig. 1.

Differential equations were set up for the simultaneous growth and decay of various fission products being produced by an expanding nuclear economy. The solutions give the accumulated

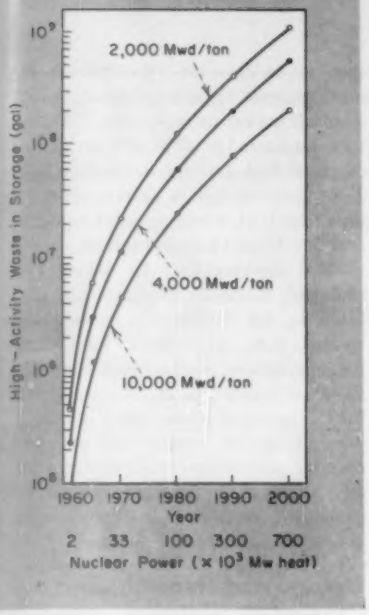

FIG. 4. Accumulated volume of high-activity waste. Curves are based on 820 gal of high-activity waste per ton of fuel processed

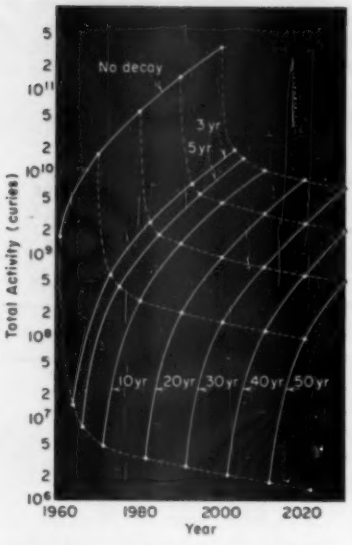

FIG. 5. Accumulated activity. Dashed decay lines are used to determine accumulated activity following any specified cooling period

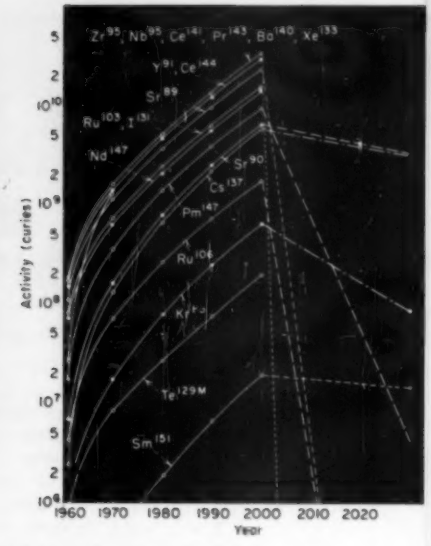

FIG. 6. Accumulated activity of important fission products in predicted nuclear economy. Dashed lines indicate decay of accumulated activity

curies of a fission product at any time between 1960 and 2000. It should be emphasized that the activities plotted are not only the activities to be found in waste-disposal tanks but include fission products present in the reactors and in fuel being stored prior to processing. This is especially important for the shorter-lived isotopes such as Ba^{140}.

In Figs. 2 and 3 are plotted predicted processing-capacity requirements. Figures 4–6 show accumulated radioactive wastes, and Fig. 7 the accumulated plutonium activity. Accumulated activity means the integrated production of fission-product activity with time minus loss by decay and by neutron capture while in the reactor.

TABLE 1—Cost of Tank Storage of Liquid Waste

Rate for fixed charge (%)	*Unit cost ($/gal/yr)*		
	Fixed charge	*Direct charge*	*Total*
$0.25/gal initial investment			
15	0.038	0.003	0.041
12	0.030	0.003	0.033
4	0.010	0.003	0.013
$2.00/gal initial investment			
15	0.30	0.003	0.30
12	0.24	0.003	0.24
4	0.08	0.003	0.08

Capture is negligible, making the curves essentially independent of reactor design and operating conditions. The activity can be considered as being dumped into and accumulated in a common "sink."

With respect to the waste-disposal problem, the amount of plutonium in storage is several orders of magnitude less than the Cs^{137} and Sr^{90} in storage. Thus plutonium becomes the limiting factor on permitted dispersal of aged wastes only after removal of Cs^{137} and Sr^{90}.

Allowable Waste-Disposal Cost

The limits on the tolerable cost per initial gallon of liquid radiochemical process waste can be defined as a function of

1. Reactor operating and design characteristics.
2. The radiochemical separations process employed.
3. The fraction of 8 mill/kwh power that is allocated to the disposal of wastes.

It has been said that ultimate disposal of radioactive liquid wastes, particularly those resulting from the processing of spent reactor fuels, would place a significant economic burden on the future nuclear power economy (*5*). Waste-disposal costs of the order of $1 per initial gallon of liquid wastes resulting from the standard solvent-extraction separations processes seemed to be an upper limit. These cost limits do hold for certain reactor-processing complexes, but are for the most part not in accord with the characteristics of the contemplated nuclear power economy.

It is our purpose here to indicate the allowable cost limits in the more general case, taking pertinent reactor-process-

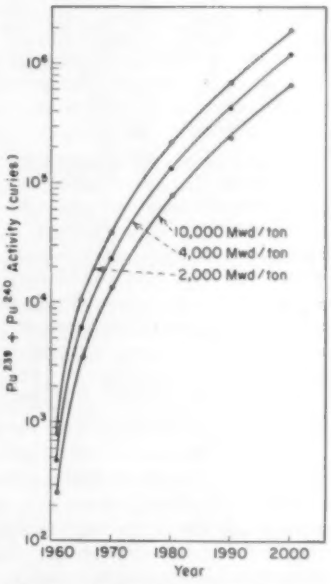

FIG. 7. Accumulated plutonium activity. Curves are based on 1% process loss of plutonium

TABLE 2—Fission-Product Activities at Discharge from Reactor

Nuclide	λ_i	Y_i	Curie/watt reactor power for operating times of: 80 days	160 days	320 days	400 days
$Ba^{140}(La^{140})$	0.0541	0.063	0.052	0.053	0.053	0.053
Nb^{95}	0.0198	0.064	0.042	0.051	0.054	0.054
Zr^{95}	0.0107	0.064	0.031	0.044	0.052	0.053
$Ce^{144}(Pr^{144})$	0.00239	0.061	0.0087	0.016	0.027	0.031
Cs^{137}	5.75×10^{-8}	0.059	2.5×10^{-4}	4.5×10^{-4}	8.9×10^{-4}	1.1×10^{-3}
$Ru^{106}(Rh^{106})$	0.0019	0.0038	4.5×10^{-4}	8.3×10^{-4}	1.5×10^{-3}	1.7×10^{-3}

TABLE 3—Activity in Liquid Waste for Various Cooling Times*

Nuclide	γ energy (Mev)	Gamma yield (%)†	γ curies/gal for cooling time of: 100 days	500 days	1,000 days	3,000 days	10,000 days	30,000 days
La^{140}	3.0	1	0.068					
	2.5	5.4	0.37					
	1.5	94	6.4					
Nb^{95}	0.75	100	240	0.084				
Zr^{95}	0.73	100	560	7.4	0.035			
Pr^{144}	2.2	1	7.7	3.1	1.0	1.4×10^{-4}		
	1.5	2	15.4	6.2	2.0	2.8×10^{-4}		
	0.7	4	30.8	12	4.0	5.6×10^{-4}		
Cs^{137}	0.66	92	31	31	29	23	18	6.2
Rh^{106}	2.4	0.25	0.11	0.053	0.020			
	1.6	0.5	0.22	0.11	0.041			
	1.0	2	0.86	0.41	0.16			
	0.9	1	0.43	0.21	0.08			
	0.6	12	5.2	2.5	0.97			

* Based on 400-day irradiation, 25 Mw/ton, and 800 gal/ton waste.
† Percentage of decays of nuclide yielding gammas of stated energy.

ing-cost variables into consideration.

Figure 8 gives the allowable disposal cost per initial gallon of waste as a function of the burnup of the spent reactor fuel that is being processed. These calculations are based on an electrical power cost of 8 mills/kwh. The curves were derived using values representative of the reactor and processing characteristics now being proposed for an economic (low-enrichment) nuclear power economy. A similar curve using values of the variables representative of a premium power (high-enrichment) economy is plotted in Fig. 9.

Allowable costs for waste disposal can vary from $0.80 to $80 per gallon for a low-enrichment economic nuclear power economy and from $0.08 to $4.80 for a high-enrichment power economy, depending on the reactor and process characteristics and on the fraction of the total cost of power allocated to waste disposal.

Although both high-activity and low-activity wastes result from processing reactor fuels, and low-activity wastes will presumably be cheaper to dispose of, no differentiation was made in Fig. 8. Therefore, on the assumption that one-fourth of the allocated portion of the total power cost went for low-activity disposal, another series of curves shown in Fig. 10 was determined to indicate the allowable cost of disposing of low-activity wastes.

The shaded area in Fig. 8 probably well represents an average of the operating characteristics of reactors and chemical processes that will exist in an economic low-enrichment nuclear power economy. From this area, it can be shown that as the allocated portion of the total power cost varies from 1% to 10% (i.e., 0.08–0.80 mill/kwh_e), the allowable cost for waste disposal will vary between $1.60 and $64 per gallon.

Since there are many areas in the economic picture of nuclear power that may be in error to 3% or more, an allocated cost for waste disposal of 3% does not appear unreasonable. Therefore, a cost range of $5–$20 per gallon of initial high-activity waste may be a better basis to use in determining the direction that waste-disposal research and development should follow.

It is obvious that to reduce the stringent economic requirements dictated to the disposers of radioactive wastes (i.e., geologists, biologists, oceanographers, sanitary engineers, designers of tanks, pits, and fancy gadgets for treatment of wastes, etc.) it is necessary to design reactors with even increasing processing-cycle times and design chemical processes with ever decreasing volumes of wastes per unit weight of reactor fuel processed.

Storage and Shipping Costs

One of the potentially attractive schemes for the ultimate disposal of radioactive waste is simply to pour the waste into pits. The best geological location for these pits may not coincide with the optimum location for a processing plant and transport will be required.

It may be necessary or desirable to remove some fission products from the waste, particularly the long-lived ac-

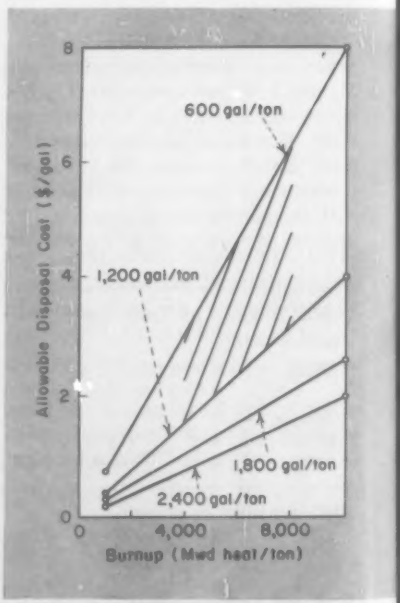

FIG. 8. Allowable waste disposal cost as function of burnup and process-waste volume—0.08 mill/kwh_e (1% power cost) allocated to disposal

TABLE 4—Storage and Shipping Costs as Functions of Cooling Time

Cooling time (yr)	Storage cost ($/gal)			Shipping cost ($/gal)		
	$0.013/gal/yr	$0.041/gal/yr	$0.30/gal/yr	200 mi	500 mi	1,000 mi
0.5	0.006	0.02	0.15	1.70	3.16	5.46
5	0.06	0.20	1.50	0.74	1.37	2.38
6	0.08	0.25	1.80	0.55	1.02	1.77
7	0.09	0.29	2.10	0.49	0.91	1.58
10	0.13	0.41	3.00	0.44	0.82	1.42
15	0.19	0.61	4.50	0.42	0.78	1.35
20	0.26	0.82	6.00	0.41	0.76	1.32
30	0.39	1.23	9.00	0.40	0.74	1.29

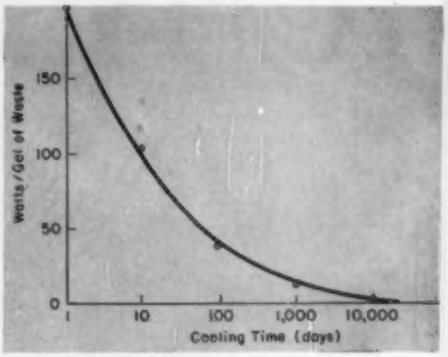

FIG. 11. Waste-heat generation of discharged reactor fuel. Based on infinite irradiation time at 25 Mw/ton and 800 gal waste per ton

tivities, prior to ground disposal. The influence of fission-product removal on shipping costs will depend on which elements are removed and to what extent. Since no firm flowsheet has been generally accepted for this step, its effect on waste-disposal economics is not considered here.

As waste is cooled, the cost of storage increases, and the cost of shipping decreases by virtue of having to ship less shield weight. The optimum cooling time will depend on the irradiation history of the fuel, the cost of storage, and the cost of shipping.

Storage costs. Tank storage of liquid wastes may be an essential step in a scheme for ultimate waste disposal. Storage reduces the heat generation and radiation problems attendant with shipping and subsequent processing. As an example, the rate of heat generation for fuel irradiated a long time (to fission-product saturation) at 25 Mw/ton is shown in Fig. 11 as a function of cooling time; 800 gal of waste per ton have been assumed.

To determine an optimum storage time to be employed in the over-all storage-shipment-treatment-disposal cycle, an estimate of the cost of storing a unit volume per unit time is necessary. The following assumptions were made:

1. Lifetime of underground storage tank of 50 yr
2. Purex-type waste
3. Tank farm operating personnel of 2 men/shift

Fixed charges were calculated for initial investments of $0.25 and $2 per gallon at three different annual rates: 12% and 15% per year represent the range used by utility companies to write off investments, including profit, taxes, and interest on capital; 4% per year might be the rate for a government-owned burial site (2% amortization plus 2% average interest).

The cost of land [($5,000/acre)/(1,000,000 gal/acre) = $0.005/gal] was neglected compared to the initial cost of tankage.

Direct operating costs (based on a 20,000,000-gal form that has reached steady state) will be

$$\frac{2\text{ men/shift} \times 4\text{ shifts} \times \$4500/\text{man-yr}}{20{,}000{,}000\text{ gal}} = \$0.0018/\text{gal/yr}$$

Allowing for 67% overhead, the direct charge will be $0.003/gal/yr. The calculated unit charges for the six cases are given in Table 1.

Shielding for shipment. The number of curies of a fission product per watt of reactor operating power will be

$$\frac{\text{curies}}{\text{watt}} = \frac{3.1 \times 10^{10}\text{ fiss/sec/watt}}{3.7 \times 10^{10}\text{ dps}} \times (Y_i)(1 - e^{-\lambda_i t_0})(e^{-\lambda_i t_c}) = 0.84\, Y_i(1 - e^{-\lambda_i t_0})e^{-\lambda_i t_c}$$

where Y_i = fraction fission yield, λ_i = decay constant (day^{-1}), t_0 = reactor operating time (days), and t_c = cooling time (days).

Based on Project Separations(4) tab-

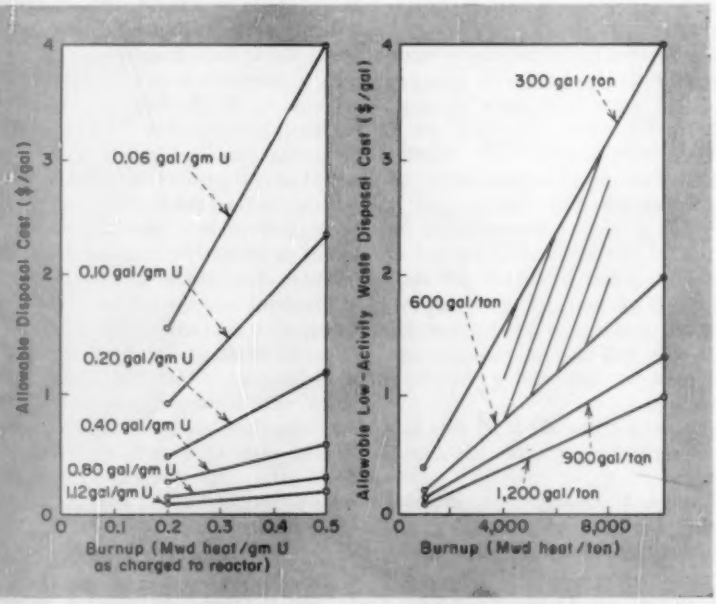

FIG. 9. Allowable waste disposal cost for highly enriched (premium power) reactors—1% power cost allocated to disposal

FIG. 10. Allowable disposal cost for low-activity waste—based on allocation of 0.25% power cost to waste disposal

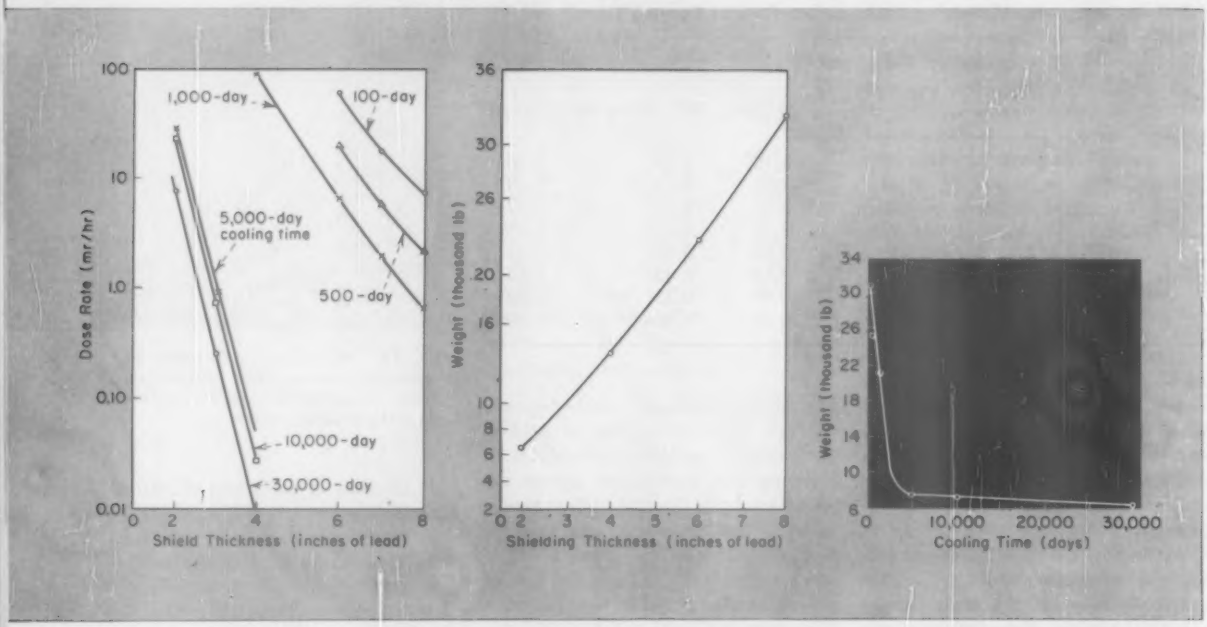

FIG. 12. Dose rate at car wall for various cooling periods and shield thicknesses. Based on 400-day irradiation to 10,000 Mwd/ton

FIG. 13. Weight of spherical lead shipping carrier (4-ft i.d. and 250-gal nominal capacity) as function of shield thickness

FIG. 14. Shield weight to give 10-mr/hr surface dose (250 gal in 4-ft-i.d. sphere; 800 gal waste per ton, 400-day irradiation to 10,000 Mwd/ton)

ulation a typical reactor specific power of 1,000 Mw/40 ton = 25 Mw/ton is assumed. On this basis, the reactor operating time would be 80, 160, 320, and 400 days for 2,000, 4,000, 8,000, and 10,000 Mwd/ton, respectively.

Fission products to be considered for the shielding calculations are Ba^{140} (La^{140}), Zr^{95}, Nb^{95}, Ce^{144} (Pr^{144}), Cs^{137} and Ru^{106} (Rh^{106}). Table 2 gives the number of curies of each of these fission products present at time of discharge from the reactor for various reactor operating times.

Since 800 gal of high-activity waste per metric ton and a specific power of 25×10^6 watts have been assumed, curies/gal = A(curies/watt) $\times$ 2.5 $\times$ $10^7/800 = 3.1 \times 10^4 A$. The specific activities are listed in Table 3 for 400-day irradiation at 25 Mw/ton.

Shielding calculations were made for a 4-ft i.d. carrier holding 250 gal of waste from fuel irradiated 400 days (10,000 Mwd/ton). A maximum permissible dose rate of 10 mr/hr at the wall of a 9-ft-wide railroad car was the basis for determining the shield thickness.

Figure 12 shows the total dose rate at the car wall as a function of the cooling time.

Combined cooling and shipping costs. For a fixed irradiation, the combined cost of storage and shipping will be a function of cooling time and shipping distance.

Carrier weights are plotted as a function of shield thickness in Fig. 13 for a 250-gal waste capacity. Using the shield thicknesses from Fig. 12 that give a 10-mr/hr tolerance dose (for 400-day, 10,000-Mwd/ton irradiation), carrier weights are plotted as a function of cooling time in Fig. 14. It is assumed that the empty carrier must be returned to its point of origin and that carrier cost and handling charges would not be significantly influenced by cooling time compared to freight charges.

The freight charges per ton of carrier (round trip) are based on the following rates: \$1.40, \$2.60, and \$4.50 for one-way distances of 200, 500, and 1,000 miles. The optimization is carried out for these three distances and for unit storage costs of \$0.013, \$0.041, and \$0.30/gal/yr from Table 1. The basic costs appear in Table 4 and the combined results in Figs. 15–17.

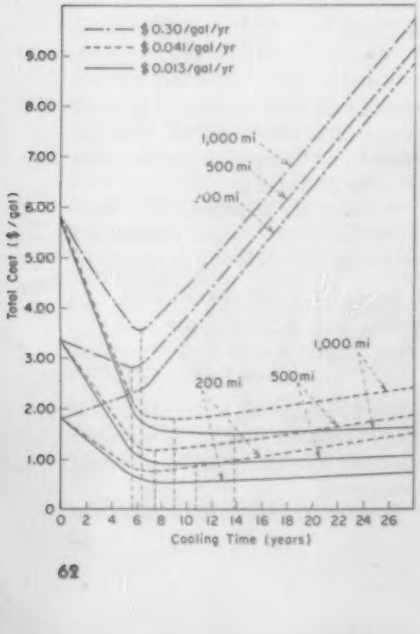

FIG. 15. Combined shipping and storage costs for storage costs of \$0.013, \$0.041, and \$0.30/gal/yr. Based on 250 gal shipped in 4-ft-i.d. sphere, 800 gal waste per ton spent fuel, 400-day irradiation to 10,000 Mwd/ton

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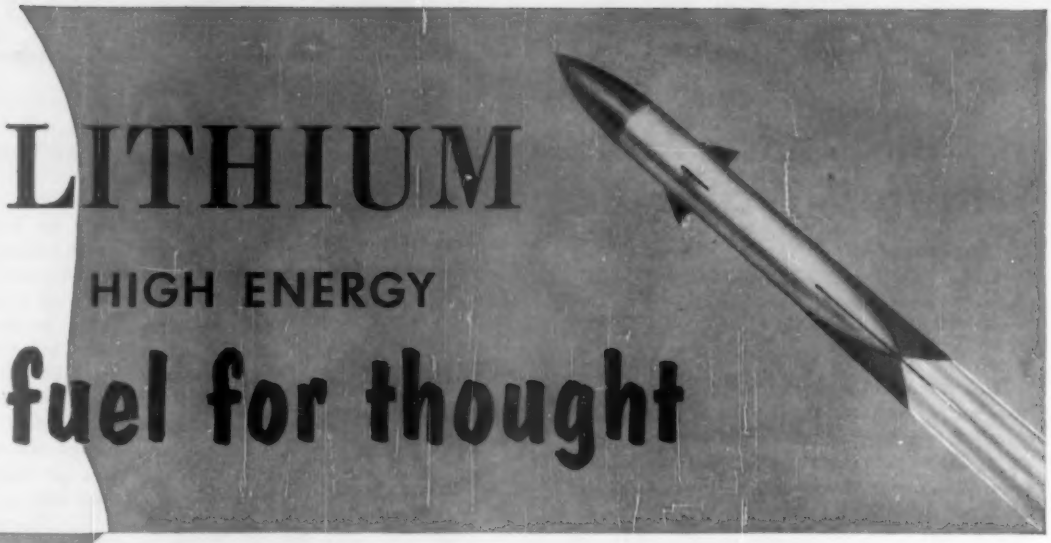

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Technique for Monitoring Tritiated-Water Vapor in Air

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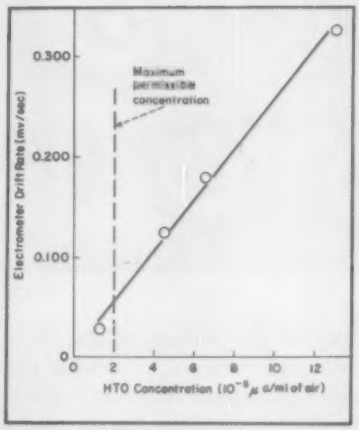
Tritium and tritiated water of very high specific activity can be readily obtained in large amounts. In areas where this material is stored or used the problem of maintaining a routine check on the HTO air contamination must be met.

Continuous air-sampling devices are fairly elaborate and expensive and although useful as warning devices, are not generally reliable for accurate determinations of HTO concentration in air (*1*). The purpose of this article is to describe a simple, accurate, and convenient method of HTO-vapor monitoring, suitable for values as low as the maximum permissible (for continuous exposure, 2×10^{-5} μc/ml of air) (*2*). The method is ideal for storage areas or locations where accurate determination of concentration is more essential than immediate warning.

Experimental Method

The method utilizes an ionization chamber of 250-cm³ capacity and a vibrating-reed electrometer for current measurement.

The ionization chamber was calibrated by filling with known concentrations of HTO vapor in air and measuring the resulting electrometer drift rate. A typical calibration curve is shown in the illustration. Known concentrations of HTO vapor in air were obtained using a flask of known capacity containing dry air at atmospheric pressure into which were introduced various concentrations of HTO in H_2O. A National Bureau of Standards tritiated water sample was used. The activity of this sample was known to within 1%. In all cases, the total water volume introduced into the flask was such that when uniformly distributed as water vapor, the relative humidity was less than the saturation value. Samples of flask air were then transferred to the ionization chamber for measurement.



TYPICAL CALIBRATION curve obtained by filling ionization chamber with known concentrations of HTO vapor in air

This simple method of calibration permits the direct use of tritiated water vapor in the ionization chamber and eliminates the need for conversion to tritium gas. Difficulties such as nonreproducibility of data and contamination have been reported (*3*) by others using tritium in the form of water vapor. In this work, however, it was found that these difficulties were mainly due to a chemical reaction of HTO with the brass chamber walls. Gold-plating all interior surfaces of chamber and electrode eliminated the problem. In addition, a Teflon insulator was used because of its negligible water absorption.

Decontamination of the chamber was readily accomplished by evacuation accompanied by gentle heating.

After calibration the chamber itself is used as a portable air sampler by carrying it (evacuated) to the desired location and opening it to the room air to be tested. The calibration curve converts the electrometer reading of the air sample directly into HTO concentration. Concentrations lower than the maximum permissible can readily be determined with an error of less than 10%.

Discussion

The internal hazard from gaseous tritium is not great because there is little absorption through lung tissue or skin (*4*, *5*). However, the oxides (HTO, T_2O) always associated with the release of tritium gas are readily absorbed through lungs and skin and uniformly distributed throughout the body (*6*, *7*).

The method of chamber calibration described here, therefore, is advantageous in that the response of the chamber is directly proportional to the total activity, including the most hazardous form of tritium, that is, HTO vapor.

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Ionization-Chamber Method of Measuring Mixed γ-n Fields of Known Energy

By KERAN O'BRIEN
and J. E. McLAUGHLIN, Jr.
Health and Safety Laboratory
New York Operations Office
U. S. Atomic Energy Commission
New York, New York

Stray-radiation surveys have been conducted at particle-accelerator sites by the Health and Safety Laboratory since early 1953. The impetus for this program was supplied by the reports of the occurrence of neutron cataracts in cyclotron workers (*1*) and by the great increase in the numbers of particle accelerators under contract to the Atomic Energy Commission. A summary of the survey work performed in 1953 and 1954 has been reported (*2*).

In the early surveys, neutron and X-ray measurements were made solely with the usual portable ionization chambers and scintillation and propor-

another reactor monitoring service . . .

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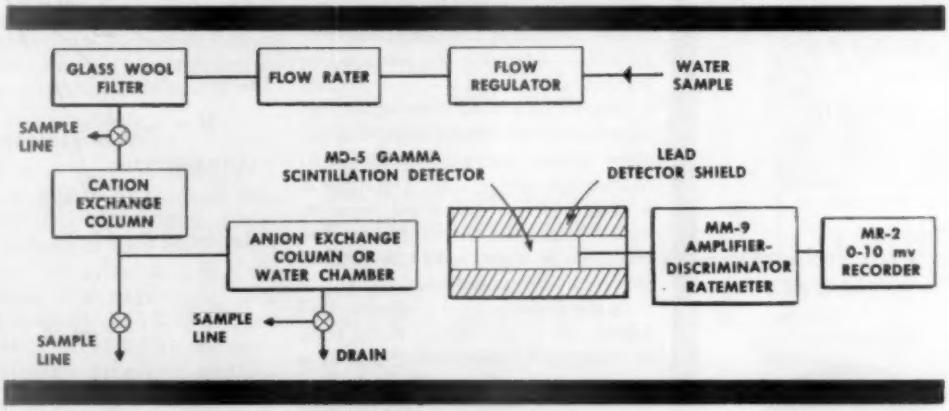

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tional neutron counters. Since 1955, ionization chambers, used in conjunction with vibrating-reed electrometers, have constituted the major portion of the survey equipment.

Ionization chambers have many desirable features for field work. They are relatively rugged, insensitive to radiofrequences, and measure energy absorption in a real sense. If two or more ionization chambers of differing atomic composition are exposed to mixed fields of radiation, it is possible to determine the X-ray dose and the neutron flux providing the energies of these are known. The response of an ionization chamber to a mixture of X- or γ-radiation and fast neutrons is

$$R = k\gamma + g\phi \qquad (1)$$

While it is possible to evaluate k directly using a gamma-ray source, the usual neutron sources have a gamma-ray contamination that must be taken into account (*3*). The method described in this paper was applied to the determination of both the gamma and the neutron activity of a Po-Be neutron source, and is in fact applicable to any mixed gamma-neutron field where the energies of these are known within the limits of the energy assumptions implicit in the mathematics.

Ionization Chambers

Two ionization chambers were employed to determine the neutron and gamma intensities of the Po-Be source.

One, a Failla-Rossi tissue-equivalent chamber, has a wall and filling with the same gross atomic composition as average wet tissue (*4*). The other is a graphite-walled CO_2-filled chamber, with a wall thickness of $\frac{3}{8}$ in. The chamber is surrounded by $\frac{1}{16}$-in. aluminum for gas tightness.

In the mathematical treatment that follows, the energy deposition per gram of filling gas is determined, and as a consequence it is necessary to assume that the walls and fillings have the same atomic composition.

Mathematical Discussion

When a material of a polyatomic composition is bombarded by neutrons of energy E, the energy deposition is

$$D = \sigma_1 N_1 E'_1 + \sigma_2 N_2 E'_2 + \cdots \qquad (2)$$

on a first-collision basis. Since (assuming S-wave scattering only)

$$E' = 2AE/(1 + A)^2 \qquad (3)$$

for the relationship between the energy of the recoil nucleus and the energy of the incident neutron, Eq. 2 becomes

$$D = 2E \sum_{i=1}^{n} \frac{\sigma_i N_i A_i}{(1 + A)^2} \qquad (4)$$

The molecular weight is

$$M = x_1 A_1 + x_2 A_2 + \cdots \qquad (5)$$

and we may write

$$N_i = (L/M)x_i \qquad (6)$$

Substituting Eq. 6 in Eq. 4

$$D(E) = \left[\frac{2EL}{M}\right] \sum_{i=1}^{n} \frac{\sigma_i x_i A_i}{(1 + A_i)^2} \qquad (7)$$

Let $p(E) = B/D(E)$. Then

$$p(E) = \frac{8.68M}{EL}\left[\sum_{i=1}^{n} \frac{\sigma_i x_i A_i}{(1 + A_i)^2}\right]^{-1} \qquad (8)$$

If the neutrons have some known energy distribution $N(E)$, then

$$p = \frac{\int_0^{E_{max}} N(E)\,dE}{\int_0^{E_{max}} N(E)/p(E)\,dE} \qquad (9)$$

Returning to Eq. 1, if γ is in units of mrad/hr, we can write the response for two ionization chambers (providing that the energy for ionization is pro-

Table of Symbols

- A = mass number of recoil nucleus
- E = energy of incident neutron (Mev)
- E' = energy of recoil nucleus (Mev)
- σ = microscopic cross section (cm^2)
- N = number of nuclei per gram
- ϕ = neutron flux ($n/sec/cm^2$)
- L = Avogadro's number
- M = molecular weight
- x = number of atoms of mass A per molecule
- p = neutron flux that deposits 1 mrad/hr
- $p(E)$ = neutron flux of energy E that deposits 1 mrad/hr
- $N(E)$ = relative number of neutrons with energies in the interval E to $E + dE$
- $D(E)$ = energy deposition per gram per neutron for neutrons with energy E
- B = conversion constant, 17.34 (Mev/gm/sec)/(mrad/hr)
- R = ionization-chamber response, proportional to ion current
- γ = γ-ray dose rate (mrad/hr)

vided by elastic collision only) as

$$R_j = k_j\gamma + (k_j/p_j)\phi \qquad (10)$$

where $j = 1, 2$. This will give

$$\phi = \frac{p_1 p_2}{(p_1 - p_2)}\left(\frac{R_2}{k_2} - \frac{R_1}{k_1}\right) \qquad (11)$$

$$\gamma = \frac{1}{(p_1 - p_2)}\left(\frac{R_1 p_1}{k_1} - \frac{R_2 p_2}{k_2}\right) \qquad (12)$$

To apply Eqs. 11 and 12 to the Po-Be source, and to the ionization chambers described above, $p(E)$ for tissue was taken from the data of Hurst (*5*), and p determined by means of Eq. 9, integrating with Simpson's rule at 0.2-Mev intervals over the spectrum of Whitmore and Baker (*6*). Similarly, for CO_2, $p(E)$ was determined from Eq. 8. The calculation of p was carried out exactly as for tissue. The results were $p = 498.9$ and 67.70 (n/sec/cm²)/(mrad/hr) for CO_2 and tissue, respectively.

We determined k_j with a standard encapsulated Ra^{226} source, assuming 93 ergs per gram of chamber filling per roentgen, and assuming that one mrad of Ra^{226} gamma radiation and one mrad of C^{12*} gamma rays produced identical numbers of ion pairs in both chambers. As the above treatment presupposes nonrelativistic velocities for the incident neutrons, and *S*-wave scattering only, it delimits neutron energies to the region below about 15 Mev and chamber materials to the light elements as its range of applicability.

Experimental Results

The neutron source strength (when normalized to date of purchase) was determined to be 2.67×10^7 neutrons/sec, in agreement with the Mound Laboratory calibration of 2.69×10^7 neutrons/sec for the same date. The gamma contamination was determined to be 0.00417 (mrad/hr)/(n/sec/cm²).

This value for the gamma contamination has been assumed to be independent of the Po-Be source configuration and source strength. Both experimental and theoretical values have been reported (*6*), i.e., 0.00272 and 0.00137 (mrad/hr)/(n/sec/cm²) (assuming that one roentgen deposits 93 ergs per gram of tissue).

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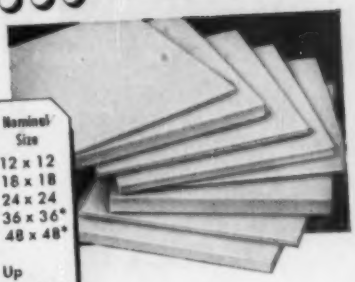

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1/4	48 x 48*
3/8	
1/2 & Up	

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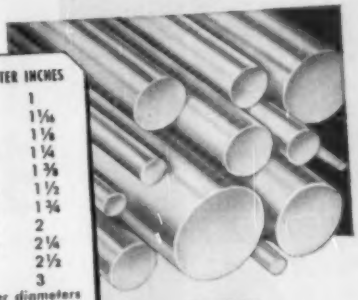

DIAMETER INCHES	
1/4	1
5/16	1 1/4
3/8	1 1/2
7/16	1 1/4
1/2	1 3/4
9/16	1 1/2
5/8	1 3/4
3/4	2
7/8	2 1/4
	2 1/2
	3

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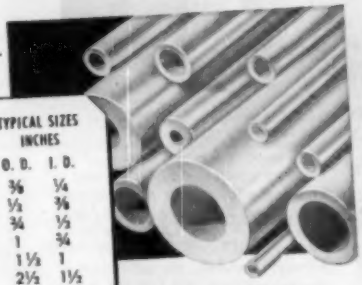

TYPICAL SIZES INCHES	
O. D.	I. D.
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1/2	3/8
3/4	1/2
1	3/4
1 1/2	1
2 1/2	1 1/2
3	1 3/4

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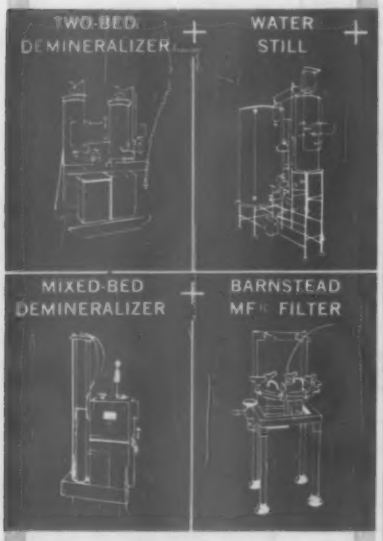

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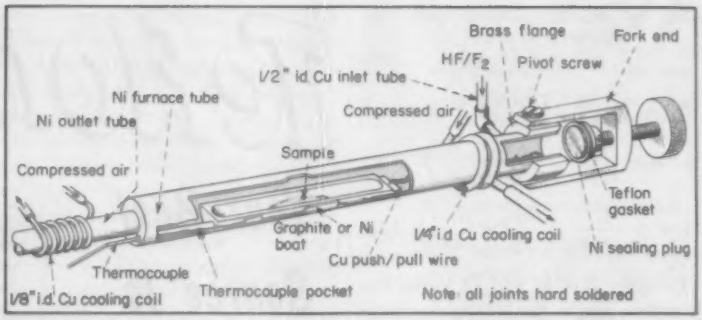

FLUORINATION reaction tube. In operation, tube is positioned inside nichrome-wound furnace

Dry-Way Fluorination Under Glovebox Conditions

By K. R. HYDE and D. J. O'CONNOR*
Atomic Energy Research Establishment
Harwell, Berkshire
England

The gaseous diffusion method of separating the natural U^{235} and U^{238} isotopes utilizing volatile uranium hexafluorides (B.P., 56.5° C at 760 mm Hg) is well established (*1*). Recently the importance of the decontamination and recovery of irradiated uranium fuel using uranium hexafluoride has been outlined (*2, 3*).

Small quantities of gaseous anhydrous hydrofluoric acid and fluorine are often required on a laboratory scale for this type of chemical processing, and also for preparing fission product and other metallic fluorides not usually available in a high state of purity. In this connection, it is desirable to study gas-solid reactions at elevated temperatures (up to 650° C) using HF, F_2 and irradiated and toxic materials.

For such studies, an all-metal apparatus consisting of a nickel reaction tube and gas feed and effluent lines of copper was constructed. This apparatus has been successfully used in systems containing 2 curies of α, β, γ activity, and also for studying reactions of beryllium compounds. The health precautions necessary in handling the latter are stringent (*4*), and for this reason hydrofluorination and fluorination of these compounds were performed under glovebox conditions.

Many of the techniques described here have been developed over the years by staff of the Chemistry Division, AERE Harwell, and the apparatus is based on the experience of several workers (*5–7*).

Apparatus

The apparatus used for both the dry-way hydrofluorination and the fluorination of solid materials are very similar in design, differing only in metering and disposal of exhaust gases. The reaction tube is shown in the drawing.

Glovebox. The glovebox used is a standard type in use at AERE Harwell, 6 × 3 × 3 ft, mounted on a Dexion stand, and maintained at 1-in. water gage negative pressure. It has two working sides with beaded-type gloves (*8, 9*). The polyvinylchloride-bag transfer technique is available for inserting and removing equipment. The box is also fitted with a two-door transfer port, 21 × 10 in. Because of their proximity to the furnaces, the gloves are held to the outside of the box by Terry clips when not in use.

As no free HF or F_2 gas was allowed into the box proper, the rubber gloves did not perish and had a normal working life (about 2 months).

Hydrofluorination apparatus. The HF gas for the study of gas-solid reactions at elevated temperatures was obtained from a 6-lb I.C.I. cylinder in a thermostatically controlled water bath (normally operated at 35° C). The feed lines to the furnace were of ¼-in.-nominal-bore copper tubing with junctions and connections made with either Kontite or Teflon-gasketed AERE vacuum fittings. Rubber gaskets have proved unsatisfactory with both HF and F_2. A T-junction at the cylinder

* Australian Atomic Energy Commission.

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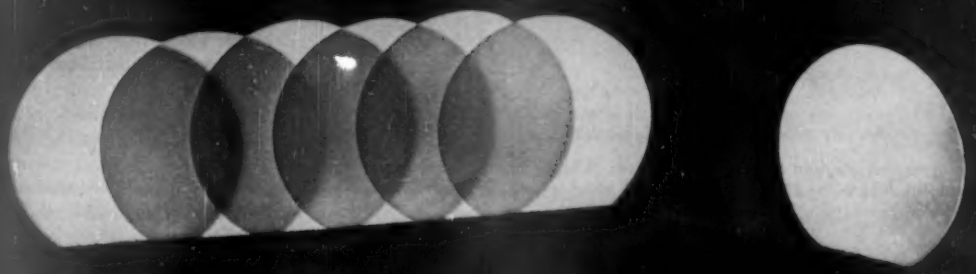

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exit was fitted with a brass steam valve modified with Teflon gaskets. This allowed purging of the gas lines and reaction furnace with an inert gas. The gas line was maintained at not less than 30° C by asbestos-lagged heating tape to avoid condensation of the HF gas (B.P., 19.4° C).

The HF gas was metered using a choked-orifice meter placed midway between the cylinder and reaction furnace. The meter consisted of a 1-in.-diameter nickel tube on the exit end of which was fitted a platinum disk having a 0.006-in.-diameter central hole.

The gas is maintained in a monomolecular state by heating the nickel tube to about 80° C in a wire-wound furnace. The gas flow rate can be controlled by varying either the cylinder bath temperature or the orifice diameter to give any desired flow rate up to 100 gm anhydrous HF per hour.

The reaction vessel was essentially a 1½-in.-i.d., 14-in.-long nickel tube with all joints hard soldered, heated in a variac-controlled wire-wound 2-kw furnace. To maintain corrosion-free joints, a high-silver-content hard solder is essential. The furnace head was sealed by a nickel plug with a Teflon gasket operated by a gate-clip-type assembly. Both ends of the furnace were cooled by compressed-air cooling coils. Water cooling is unsatisfactory due to condensation of liquid HF in the pipe line. Graphite boats were normally used to contain the sample, but welded-nickel boats have also been used satisfactorily. A thermocouple pocket was built into the reaction tube. In this apparatus gas-solid reactions have been studied up to 650° C, although, using a welded reaction furnace, investigations have been made up to 900° C.

Excess HF and gaseous reaction products were disposed of by passing through polythene tubing into a water-cooled all-polythene condenser (*10*). The condensed HF siphoned automatically into a polythene bottle containing saturated KOH solution placed at a lower level than the condenser. This condenser assembly was vented externally through the glovebox to a fume hood.

Fluorination apparatus. Fluorine gas was obtained from a 10-ampere, 10-volt I.C.I. fluorine generator, and was metered by passage through a Brown and Kronberger type mass flowmeter (*11*) with a $\frac{1}{16}$-in.-i.d. central copper tube. Flow rates were 10–70 ml/min at N.T.P. The gas lines and

fittings were as for the HF system, except that no heating of the lines was required. The reaction furnace was of identical design and construction. Nickel boats were, however, used in all fluorination studies. Platinum is unsuitable because of formation of PtF_4, and graphite burns in fluorine gas at the temperatures used. The excess fluorine was disposed of by passing from the glovebox to a nickel disposal unit in a fume hood, where it was burned in coal gas. The gas produced was absorbed in 10% caustic soda solution (*12*).

Experimental

Samples were 1–20 gm. The lines and furnaces were purged with inert gas (hydrogen for HF, argon for F_2), and dried by passing through a liquid-oxygen cold trap until the desired furnace temperature was reached. With HF, the flow of inert gas was then discontinued and anhydrous HF passed directly from the cylinder, but the F_2 was diluted with 2–3 times its volume of argon. The HF or F_2 gas was passed for the desired time, then cut off, and the system purged of HF or F_2 as the furnace cooled to room temperature.

Conclusions

The apparatus described in this paper have been successfully used for the hydrofluorination and fluorination of irradiated uranium and thorium systems containing up to 2 curies of α and mixed fission product (β, γ) activities. Beryllium compounds have also been investigated under glovebox conditions. By appropriate use of shielding there appears no reason why the β, γ activities handled should not be increased by a factor of five. Since the glovebox used is of standard design, systems of up to 10 curies α activity could also be investigated, but the limiting factor in this case is the neutron flux produced by the (α, n) reaction on fluorine.

The equipment has given trouble-free performance for more than 100 hr operating time. Corrosion of the nickel, copper, Teflon, and polyethylene components has been virtually negligible, and maintenance simple.

* * *

Acknowledgements are gratefully made to the Chemistry Division Workshop, AERE, for manufacture of the furnace assemblies, and to the Illustration Section, AERE, for preparing the drawing.

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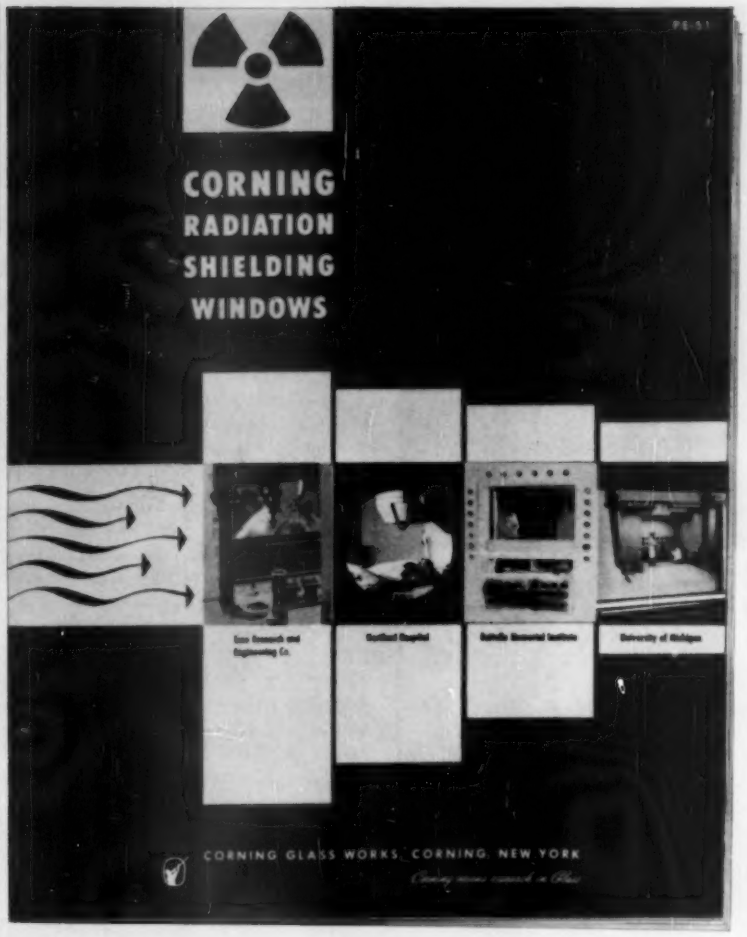

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Electrodeposition of the Actinide Elements

By ROY KO
Hanford Atomic Products Operation
General Electric Company
Richland, Washington

Thin, uniformly distributed films of radioelements are required for the measurement of various nuclear constants, for other pile-irradiation and particle-accelerator experiments, and for isotopic analysis involving alpha-particle counting, fission counting, and alpha-energy measurements. In addition, such films have been used for detecting and determining radioelements and as radiation sources for calibrating scintillation systems and proportional gamma counters.

Of the various techniques used to obtain such films (*1, 2*), electrodeposition is generally considered to be one of the best.

Most of the work on the electrodeposition of the actinide elements has been on uranium (*3, 4*) and plutonium (*5–7*). In the most widely used method (*3*), uranium is quantitatively precipitated as a hydrous oxide film at a platinum cathode from an ammonium oxalate solution. Uranium has also been deposited on mercury (*8*) aluminum (*9*) and nickel and Monel metal (*10*).

Plutonium deposition on mercury has been reported (*11, 12*), although Cook (*13*) found no significant results by mercury-cathode electrolysis. In addition, plutonium has been deposited from nitric acid (*11, 14, 15*), sulfuric acid (*16*), sodium chloride (*17*), and ammonium oxalate (*7*) solutions, and from alkaline carbonate, potassium hydroxide, and ammonium chloride-ammonium hydroxide (*2*).

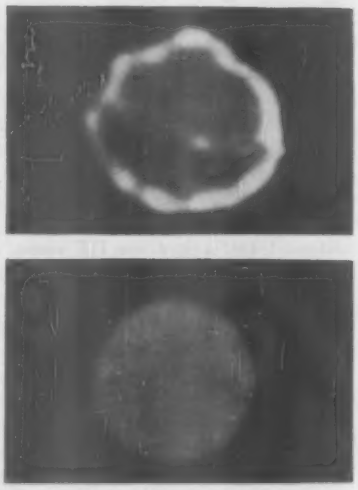
Not many investigations on the electrodeposition of the other actinide elements have been made. Actinium and thorium have been deposited from an alcohol-acetone solution (*18*) and protactinium has been investigated (*19*).

Thorium has been deposited as a mixed organic-metallic compound from organic solvents containing zinc chloride (*20*). It has been deposited from aqueous solutions containing thorium as an organic acid salt (*21–23*), as a fluoborate (*21, 24*) or as a fluosilicate (*21*). It has also been deposited by the cathodic precipitation of thorium ferrocyanide (*3*), by the anodic precipitation of thorium hydroxide (*25*), and by mercury-cathode electrolysis (*12*).

The conditions for neptunium deposition are similar to those for uranium (*13*). Neptunium has been deposited at a mercury cathode (*26, 12*), from lithium fluoride (*2*), and from ammonium oxalate (*27*).

Work on americium and curium has been reviewed (*28*).

In these methods, the highly electropositive actinide elements have been deposited from aqueous solutions as an



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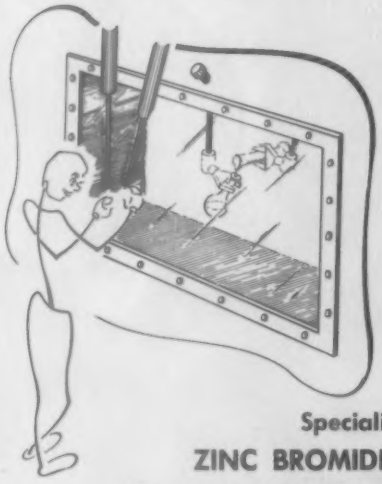

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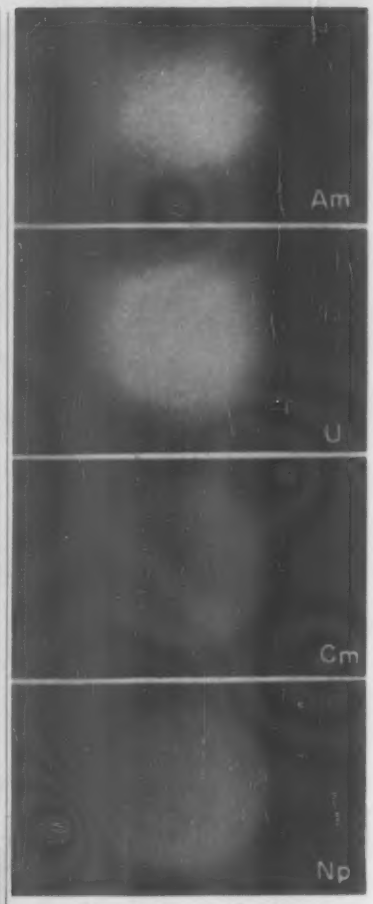


AUTORADIOGRAPHS of electrodeposited disks. 78,000 dpm Am^{241} on stainless steel. 22,600 dpm U^{235} on platinum. 11,000 dpm Cm^{242}–Cm^{244} on stainless steel. 5,800 dpm Np^{237} on platinum

insoluble compound at one of the electrodes.

The author has investigated the precipitation of metal hydroxides at the cathode by the electrolytic formation of base and successfully deposited thorium, uranium, neptunium, plutonium, americium, and curium by this technique. The electrolyses have been made in various acid solutions containing ammonium formate. The presence of formate reduces hydrogen-ion formation at the anode and makes the quantitative precipitation of the metal hydroxides at the cathode possible. A description of the technique follows.

Experimental

The apparatus used for the electrolysis have been described elsewhere (*6*). All experiments were made at room temperature. The deposition yields

of the elements, except thorium, were calculated from measurements of the radioactivity of the electrodeposits. Thorium yields were calculated from the weights of the deposits.

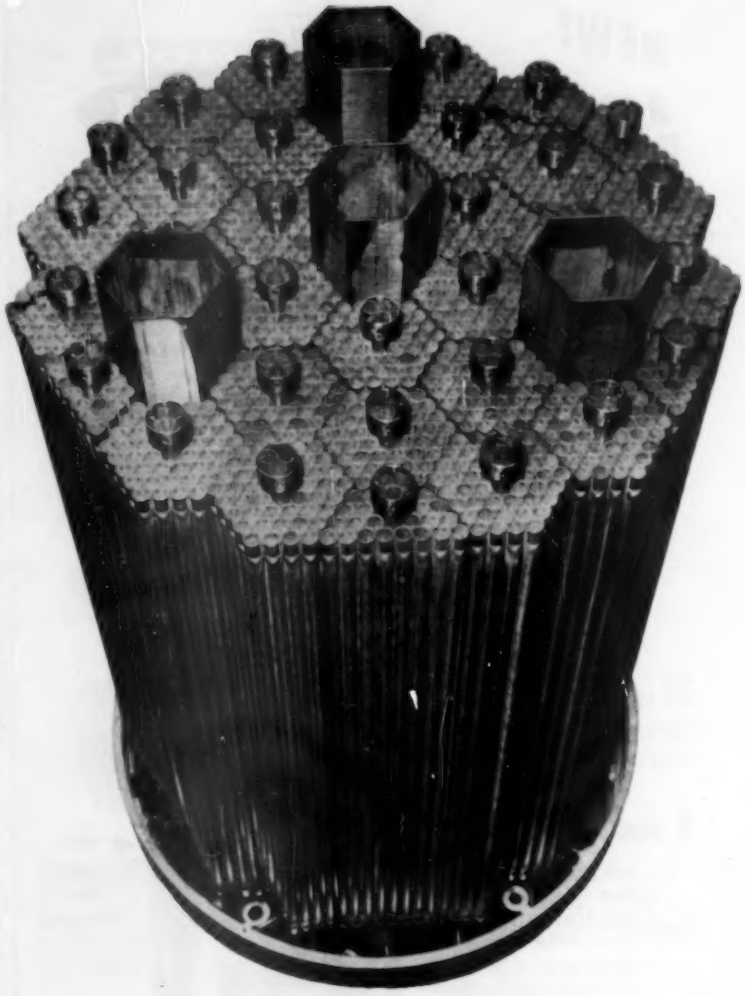
The electrodeposits were made on metal-disk cathodes 1.5–10 cm^2 in area by adding enough electrolyte to cover the platinum-anode stirrer, which was 10 mm above the cathode. A volume of sample not exceeding 10% of the volume of electrolyte was added, the anode rotated at approximately 200 rpm, and the electrolysis performed for the required length of time. At the end of the electrolysis, the solution was siphoned out, the cell rinsed with dilute NH_4OH and finally with acetone, the cell disassembled, and the electrodeposited disk ignited to redness over a bunsen flame.

Thorium. The quantitative deposition of 0.1–3 mg of thorium by cathodic base formation proved successful at a copper cathode in sulfuric acid-ammonium formate. Thorium was 100% deposited on a 38-mm-diameter copper disk at a current of 50 ma from 0.05*M* H_2SO_4-0.08*M* NH_4COOH in 16 hr and from 0.05*M* H_2SO_4-0.08*M* NH_4COOH in 50% ethanol in 4 hr. On platinum, the latter electrolyte produced a uniform, adherent deposit but a lower yield (38%) in 16 hr. With 50% methanol in place of ethanol, the yield was 67%.

Uranium. The deposition of uranium proved unsuccessful in mixtures of ammonium formate with nitric, formic, or perchloric acids at stainless steel and platinum cathodes. One hundred per cent deposition was obtained on copper and on treated platinum at a current of 80–100 ma from 0.20*M* $HClO_4$-0.15*M* NH_4COOH in 1 hr. Up to 0.7 mg U^{235} was deposited on a 6-cm^2-area cathode. The platinum was treated by boiling a few minutes in nitric acid, rinsing in distilled water, boiling in hydrochloric acid, rinsing and drying. The effect of this treatment on the mechanism of the electrodeposition was not investigated.

Neptunium. Neptunium was successfully deposited under the same conditions used for uranium. Two and five-tenths micrograms of Np^{237} was 100% deposited at a current of 80–100 ma on copper and on treated platinum from 0.20*M* $HClO_4$-0.15*M* NH_4COOH in 1 hr. The cathode area was 1.5 cm^2.

Plutonium. The deposition of the actinide elements by cathodic base formation was first demonstrated with plutonium in a nitric acid-ammonium oxalate solution (*5*). The deposition



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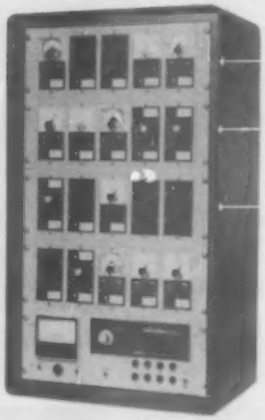

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was made on stainless steel and aluminum at a current of 320 ma from 0.25*M* HNO_3-0.10*M* $(NH_4)_2C_2O_4$ in 1 hr. Plutonium has also been deposited from ammonium formate solutions on a 1.5-cm² stainless steel cathode. One microgram of plutonium was electrolyzed at a current of 100 ma from 0.20*M* HCOOH-0.05*M* NH_4COOH with an 80% yield in 1 hr. Up to 10 μg were deposited at 100 ma from 0.20*M* $HClO_4$-0.15*M* NH_4COOH with better than 90% yields in 1 hr. Up to 115 μg were deposited at 50 ma from 0.05*M* H_2SO_4-0.076*M* NH_4COOH with 96% yields in 4 hr.

Americium. The quantitative deposition of americium from a formic acid-ammonium formate solution was previously reported (*28*). Up to 5.3 μg of Am^{241} were deposited on 1.5-cm² stainless steel, platinum, and copper cathodes at 80–100 ma from 0.20*M* HCOOH-0.15*M* NH_4COOH in 2 hr.

Curium. Curium was deposited under the same conditions used for americium. A mixture of Cm^{242}-Cm^{244} having an activity of 16,000 dpm was 95% deposited on 1.5-cm² stainless steel and copper cathodes at 100 ma from 0.20*M* HCOOH-0.15*M* NH_4COOH in 1 hr. At 60–80 ma, deposition was only 50%.

Discussion

The deposition of plutonium as $Pu(OH)_4$ and of uranium as UF_4 are examples of precipitation by changing the valence of the cation in the presence of the proper anion. In the case of plutonium, Pu^{VI} is reduced to Pu^{IV} at the cathode in the presence of potassium hydroxide and precipitates as $Pu(OH)_4$.

The deposition may also be made by altering the anion in the presence of the cation, e.g., thorium, to be deposited. Potassium ferricyanide is reduced to potassium ferrocyanide at the cathode in the presence of Th^{IV} to precipitate thorium ferrocyanide.

Another method of altering the anion is based on the evolution of hydrogen at the cathode. By their reduction, hydrogen ions are depleted in the region of the cathode causing the precipitation of the metal hydroxide. The precipitation can be made quantitative if the initial acidity of the solution is gradually lowered by this electrolytic process.

In the absence of other easily oxidizable substances, the anode reaction in aqueous solutions is the evolution of oxygen

$$2H_2O \rightarrow 4H^+ + O_2 + 4e^- \quad (1)$$

This reaction produces as many hydrogen ions as are lost at the cathode. There is no net change in *p*H of the solution. If the reaction of Eq. 1 is replaced by one that does not produce hydrogen ions, the entire solution becomes basic.

In the methods developed by the author for the deposition of the actinide elements, the oxidation of formate at the anode was substituted for the reaction of Eq. 1.

$$HCOO^- \rightarrow CO_2 + H^+ + 2e^- \quad (2)$$
$$E^0 = +0.196 \text{ volts}$$

The anodic oxidation of formate proceeds primarily by Eq. 2 up to a current density of 50 ma/cm² (*29*). This reaction produces half a hydrogen ion equivalent and the cathode reaction involving hydrogen reduction consumes one hydrogen ion equivalent per Faraday. The net cell reaction is the loss of half a hydrogen ion equivalent per Faraday. The acidity of the electrolysis solution is reduced and the quantitative deposition of the metal hydroxide is possible.

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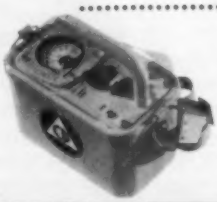

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Uranium Recovery from Saline Solutions by Biological Slimes

By EARNEST F. GLOYNA and BEN B. EWING
Sanitary Engineering, The University of Texas, Austin, Texas

Flocculant matter developed in biological waste-treatment systems is capable of removing much of the uranium, 60–90%, during continuous operations when the initial concentration of uranium is 0.098–2,000 mg/liter and the salinity approaches that of sea water. In all cases the biochemical oxygen demand (B.O.D.) reduction obtained by slimes in a sea water environment was not markedly decreased from that obtainable in common domestic wastes, which indicates the comparative effectiveness of the biological system.

The factors affecting the biological concentration of uranium by bacterial suspensions include: *p*H, length of aeration period, contact time, methods of mixing, stage of organism growth, condition of the sludges, and optimum uranium dosage for maximum uptake.

Effect of *p*H

The investigation of the effect of *p*H on uranium precipitation employed nonaerated and aerated distilled water, as well as a solution containing biological suspensions. After the *p*H of either biological solutions or distilled water was increased above 5.5, Fig. 1, the precipitates contained approximately the same amount of uranium. The initial amount of uranium in solution was 2,000 mg/l. However, the *p*H effect was not noticeable when using a uranium concentration similar to that found in some sea water, 0.002 mg/l, Fig. 2.

Effect of Mixing

The duration of mixing is especially important because it affects the rate of uranium uptake by biological sludges. When activated sludge containing 2,000 mg/l of uranium, *p*H 4.7, was aerated the greatest uptake occurred within the first 10 min of aeration. The aeration results are shown in Fig. 3.

The initial uranium uptake apparently was not caused by a change in *p*H, for the degree of self-adjustment was most measurable within 10 min of aeration. Continued aeration, 22 hr, helped to recover additional amounts of uranium. This extended aeration was most probably related to a slight increase in *p*H, 4.1 to 5.2.

Effect of Suspended Solids

Uranium pickup by microorganisms

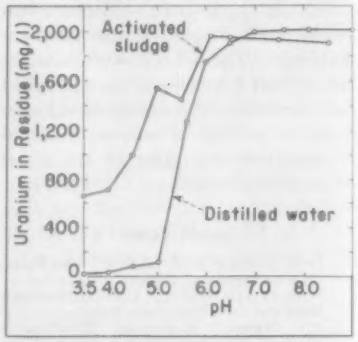


FIG. 1. Effect of *p*H on removal of uranium by activated sludge

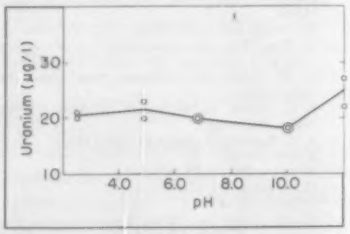


FIG. 2. Effect of *p*H on precipitation of uranium

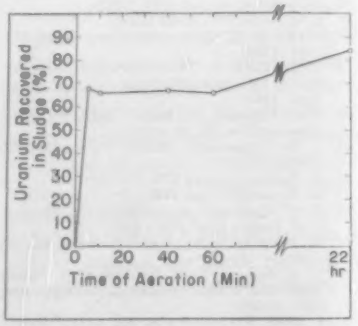


FIG. 3. Effect of aeration time on uranium pickup by activated sludge

is primarily an absorption process in which the uptake is related to both the concentration of suspended solids and the uranium concentration in accordance with the Freundlich isotherm ($X/m = KC^{1/n}$). In this expression X is the amount of uranium absorbed; m is the amount of absorbent; C is the amount of absorbate (uranium) left in solution at equilibrium; K is the constant; and n is the exponent which varies with degree of saturation of absorbate. As the absorbate becomes saturated, the value of $1/n$ approaches zero, so that the ratio X/m becomes constant.

Two such examples are given. In one case the suspended solids of an activated sludge sample were reduced to 25 and 50% of the original amount while the uranium, 2,000 mg/l, was kept constant. High concentrations of biological suspensions required acid adjustments while low concentrations required alkaline adjustment—an example of the buffering capacity of biological suspensions.

In another series of tests the suspended solids were kept constant but the uranium concentration was varied. The procedure was similar to that of the previous case except that the *p*H was adjusted to 4.2 in all samples.

In both cases the ratio of uranium removed to suspended solids (X/m) and the final equilibrium concentration of uranium in solution are as plotted in Fig. 4. The constant value of the uranium removed per unit weight of solids at high concentrations of uranium indicates that the sludge surface was saturated. The sludge used in test No. 1 had less adsorption capacity than that of test No. 2, due possibly to more extensive biological flocculation or to larger cells, which provided less effective area. Temperature and *p*H may also have influenced uranium uptake.

The saturation values of 0.13 and 0.16 found in the investigation compare with the ratio of 0.31:1 reported* for yeast cells. This comparison seems reasonable in view of the slightly larger size of protozoa and the smaller size of bacteria in activated sludge as compared with those of yeast. The actual uranium uptake per gram of yeast cells was only about one-half as much as an equivalent amount of activated sludge.

Effect of Sludge Age

The age and condition of the biological material also appears to have a bearing on the removal of uranium from solution. In these experiments the biological suspensions consisted of samples of activated sludge obtained from different locations in a biosorption process. Uranyl nitrate was added to the biological sludges, whereby a concentration of 2,000 mg/l of uranium was obtained. The *p*H was adjusted to 4.2 with nitric acid, the samples aerated for 10 min and then analyzed for uranium pickup.

The data indicate that increased biological activity results in increased uranium uptake. As shown in Fig. 5, the uranium recovered in the early phase of mixing was only 27% while the uranium recovered at the midpoint of the sludge aeration phase was about 80%. This would seem to indicate that the most active sludge was least effective in concentrating uranium; but, actually, the uptake of uranium per unit weight of sludge was greatest during this period of maximum biological activity.

Continuous Feed Plant

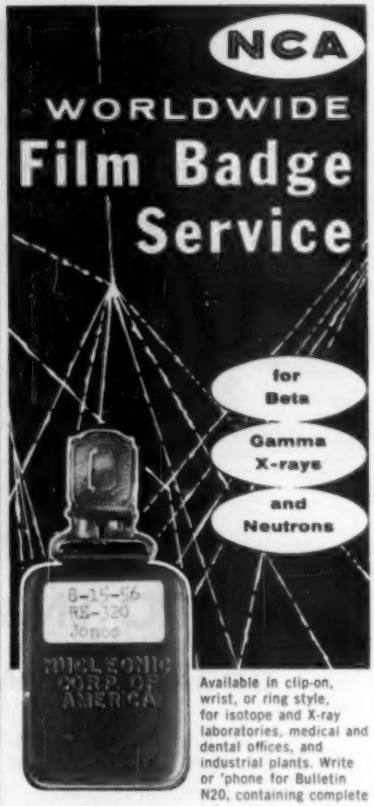
A biosorption plant, having a capacity of about 10 gal/day, was used in continuous-feed investigations.

In one series of tests a synthetic sewage contained 0.002 mg/l of uranium. A total of 0.370 mg of uranium was

* A. Rothstein, C. Larrabee, *J. Cellular Comp. Physiol.* **32**, 247 (1948).

TABLE 1—Biosorption Process

Stage no.	*Source in plant*	*Condition of organisms*
1	Effluent of sewage-sludge mixing tank, 2,444 mg/l suspended solids	Intense biological activity
2	Settled sludge, 8,584 mg/l suspended solids	Surplus of food, less biological activity due to 1–2 hr without aeration
3	Midpoint of sludge-stabilization tank, 9,364 mg/l suspended solids	Less available food, biological activity decreasing
4	End of aerobic digestion of sludge, 5,364 mg/l suspended solids	Food nearly depleted, low activity



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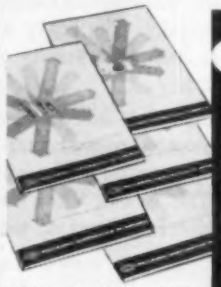

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added to the influent feed. All the effluent liquids were centrifuged and the composited sludge was sent to Oak Ridge National Laboratory for neutron-activation analyses, where it was found that this activated sludge absorbed or otherwise retained about 93% of the uranium initially fed into the plant.

In another series of tests, the same model plant was fed synthetic sewage having a salinity approximating that of sea water; a culture of salt-tolerant organisms was developed. Neutron activation analyses showed that a total of 12.3 gm of uranium were added to the influent but only 4.77 gm were recovered from the effluent—61% removal.

Mixing and Settling Unit

Considerable experimentation was also conducted with a laboratory solids-contact reactor.

Both the uranium-bearing water and excess activated sludge were fed into the top of the cylindrical reactor through an inner cone, and were intimately mixed by a stirring device. As the mixed liquor flowed out of the bottom of the inner cone and up through the annular space outside the cone, the velocity approached the settling velocity of the sludge particles. At this critical separation velocity, a sludge blanket formed that distinctly marked the separation zone. The clarified water flowed over a weir at the top and was wasted. To control the suspended solids at an optimum concentration, sludge was withdrawn periodically from the bottom of the apparatus by means of a syphon.

Four separate types of tests were made with this sludge-concentration apparatus. The test conditions are indicated in Tables 1 and 2, and the uranium removals in Fig. 6. In the case of test No. 4, a composited sample was also sent to the Oak Ridge National Laboratory for neutron-activation analyses.

In the first test, the prolonged period of starvation without aeration resulted in a decrease in biological activity. In the second test, the sludge was applied continuously but the small amount of uranium uptake was due to aging of the sludge prior to use. The sludge was collected from the treatment plant the day before and was aerated for 20 hr before the test began. This extended period of aeration resulted in depletion of nutrient and low biological activity.

A fresh biological sludge was used in the third test, and a longer operating time was used to minimize the effect of the starting period. In this latter case the uranium removal was increased to about 50%.

The fourth test was made using synthetic sea water containing 0.098 mg/l of uranium and the removal was increased to 78%. The uptake depends largely upon the total weight of suspended solids present. It is obvious that in this case the suspended solids in the sludge blanket were about twice the weight of those in the previous test.

Conclusions

1. The biological sludges in waste-treatment systems are concentrators of uranium.

2. The amount of uranium concentrated is dependent upon *p*H, activity of biological mass, quantity of suspended solids, contact time, and amount of nutrient. Temperature and concentration of uranium would affect adsorption, but these are relatively constant for sea water.

3. The activated sludge process is more efficient in concentrating uranium than are other biological treatment devices.

4. The high salinity, as found in sea water, has no effect on the uranium concentrating ability of biological systems.

5. The uranium content can be separated from highly mineralized suspensions and biological masses. However, even fluorimetric procedures are time consuming.

* * *

Work on which this article is based was performed under auspices of U. S. Atomic Energy Commission, Research and Medicine Division. The authors wish to acknowledge the efforts of Clarence Scherer (Chief of Wastewater Reclamation Plant, Amarillo, Texas) and W. R. Drynan, who, as a graduate student, participated in the preliminary investigations.

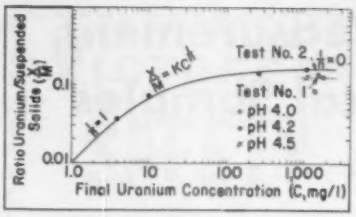

FIG. 4. Freundlich isotherm for uranium recovery by activated sludge

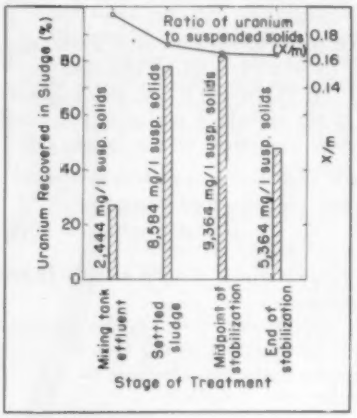

FIG. 5. Effect of growth stage on uranium recovery

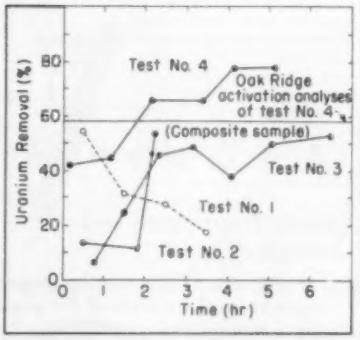

FIG. 6. Uranium removal by mixing and settling unit

TABLE 2—Conditions of Operation for Mixing-And-Settling Unit

Test no.	Solution	Concentration (mg/l)	Feed rate: Water (ml/min)	Feed rate: Sludge (ml/min)	Suspended solids in blanket (mg/l)	Age of sludge (hr)
1	Tap water	0.195	75	0	Unknown	1–5
2	Tap water	0.152	74	21	2,900	20–24
3	Tap water	0.164	74	16	3,500	1–8
4	Synthetic sea water	0.098	75	29	6,000	1–5

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Quantitative Measurement of S^{35} in Biological Samples

By R. K. PODDAR
Biophysics Division, Institute of Nuclear Physics
Calcutta, India

The S^{35} content of small samples of biological materials can be determined relatively quickly by direct counting. A self-absorption correction is made semi-empirically (*1*), using the radioactive compound in biological material as the self-absorber.

This method is more convenient than the earlier ones that usually involved counting of samples of "infinite thickness." Previously reported methods such as direct counting (*2*), alkaline peroxide or magnesium nitrate digestion (*3, 4*) and the Carius procedure (*5*) all required large specimens (a few grams) and/or prolonged chemical procedures for sample preparation. The present method saves time and is useful for measuring samples containing as little as 10^{-2}–10^{-4} μc of S^{35}.

Absorption Theory

Assume that a sample of thickness l(mg/cm²), surface area A(cm²), is placed below an end-window G-M counter. Consider an element of thickness dx at a distance x from the surface of the sample. If the specific activity of the sample is σ(μc/mg), the total activity in the element is $\sigma A dx$(μc). Now let ϵ denote the efficiency of the counting system, i.e. the fraction of the emitted beta particles actually recorded by the counter. The factor ϵ takes into account the geometry of the sample with respect to the counter as well as absorption and scattering by air and the counter window.

Assuming that ϵ is independent of the thickness of sample (which is actually very small) and that the self-absorption in the sample is exponential in nature, n, the counting rate (cpm) due to the whole sample, can be expressed as

$$n = 3.7 \times 10^4 \times 60\, \epsilon A\sigma \int_0^l e^{-\mu x}\, dx$$
$$= 2.22 \times 10^6\, \epsilon A\sigma \left[\frac{1 - e^{-\mu l}}{\mu}\right] \quad (1)$$

where μ is the self-absorption coefficient of the beta particles from the sample.

Now let us consider two cases:

(a) When $l \to 0$, i.e. the thickness of the sample is negligible compared with the range of the betas, Eq. 1 reduces to

$$n_0 = 2.22 \times 10^6 \epsilon A\sigma l$$
$$= 2.22 \times 10^6 \epsilon a \quad (2)$$

where $a = \sigma A l \equiv$ total activity in the sample.

(b) When $l \to \infty$, i.e. the thickness of the sample is greater than the range of the betas, Eq. 1 reduces to

$$n_\infty = 2.22 \times 10^6 \epsilon A\sigma/\mu \quad (3)$$

With the help of Eq. 3, Eq. 1 may be rewritten as

$$n = n_\infty(1 - e^{-\mu l}) \quad (4)$$

Rearranging Eq. 4 and taking logs

$$\mu = -(2.3/l)\left[\log_{10}\left(1 - \frac{n}{n_\infty}\right)\right] \quad (5)$$

Equations 2 and 5 give the values of ϵ and μ.

Sample Preparation and Counting

The problem of quantitative measurement of small amounts of S^{35} arose during a tracer study on the uptake by leprosy patients of diaminodiphenyl sulphone (DDS) tagged with S^{35}.

To determine the efficiency, ϵ, of the counting arrangement, 10 mg of tagged DDS was weighed out and dissolved in 100 cm³ of distilled water on a water bath. The specific activity was 1.0 μc/mg according to Harwell specifications. Aliquots of this solution, 0.05, 0.10, 0.15 and 0.20 cm³, were uniformly spread over thin grease-free 5-cm² copper planchets and dried under an infrared lamp. The planchets containing "weightless" films of tagged DDS were placed 6 mm below the shielded end-window G-M counter (2.5 mg/cm² window) and the counting rates determined.

In this arrangement the minimum detectable amount of S^{35} is 3.2×10^{-4} μc when the sample thickness is negligible. The counting rate for such a sample is twice the background (25 cpm).

To obtain the value of the self-absorption coefficient, μ, about 10 mg of tagged DDS (specific activity 1 μc/mg) was thoroughly mixed with 100 cm³ of animal blood. Various amounts of this blood were then uniformly spread as a film over previously-weighed copper planchets as described above. The blood films were dried very slowly under an infrared heat lamp. Films that turned out to be nonuniform due to relatively strong or uneven heating were rejected. The planchets were dried and reweighed. The process of drying and weighing was repeated until the final weight was constant. The weight of the blank planchet was subtracted from the final weight and divided by the film areas. The resultant film thicknesses ranged from 0.9 to 25 mg/cm². The samples were then counted by the G-M counter as before.

Results

The counting rates of the "weightless" samples were found to vary directly as their activities. For sample activities of 0.0050–0.0200 μc the corresponding counting rates were 780 ± 20 to 3,134 ± 58 cpm. The mean efficiency, ϵ, calculated from these data is only 7%.

The relation between sample thickness and the corresponding counting rate can be expressed as the ratio of counting rates of the sample and one of "infinite thickness" of the same specific activity. Results of such calculations are shown in the table.

For each thickness the self-absorption coefficient, μ, has been calculated

Self-Absorption Coefficient

Sample thickness, l(mg/cm²)	*Ratio of counting rates, n/n_∞*	*Self-absorption coefficient, μ(cm²/mg)*
0.9	0.21	0.25
2.5	0.48	0.26
5.0	0.70	0.24
7.5	0.83	0.24
10.0	0.89	0.22
12.5	0.93	0.21
15.0	0.95	0.20
17.5	0.97	0.20
22.5	0.99	0.21
25.0	1.00	
		Mean 0.225

with the help of Eq. 5. The results are shown in the last column of the table. The average value of μ is 0.225 cm²/mg. Substituting the values of μ and ϵ in Eq. 1, one gets

$$a = 10^{-6} n(1.44l)/(1 - e^{-0.225l}) \quad (6)$$

Equation 6 gives the desired interrelation between the activity, a (μc), counting rate, n(cpm), and thickness, l(mg/cm²), of the sample containing S^{35} under the given experimental conditions. It should be emphasized that μ must be independently determined for each counting arrangement.

The standard errors in counting the specimens were always within ± 1–3%. The errors in manipulation in preparing the specimens were kept within ± 5%. Hence, Eq. 6 can be taken as correct within ± 10%.

* * *

The author expresses his sincere thanks to Prof. N. N. Das Gupta, head of the biophysics division, Institute of Nuclear Physics, Calcutta, for many helpful discussions and to the Ministry of Education, Govt. of India, for financial support. Thanks are also due to Dr. K. R. Chatterjee of School of Tropical Medicine, Calcutta, for helping in preparation of specimens for counting.

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TECHNICAL BRIEF

Uranium in urine samples correlates well with air dust samples. R. L. Hoover (National Lead Co. of Ohio) reports that their hygiene department relies more on urine data because of uncontrollable variables in dust sampling—e.g., use of respirators, varying working habits, particle size, distribution of contamination, and difference in rate of metabolism of soluble and insoluble uranium.

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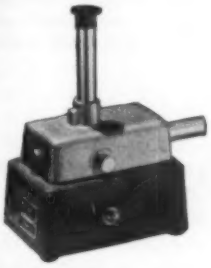

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EBR-I Core: After Meltdown

CORE CONTAINER, with fuel elements inside the hexagonal component. Internal blanket elements have been removed—they had occupied space between hexagon and cylindrical area bound by structural supporting pins, four of which are seen. At right, partition has been removed and volume of enriched uranium that melted can be seen; fusing of fuel elements is apparent. These photos were made in Idaho, next in Argonne hot lab

CLOSE-UP OF CORE, with some of fuel elements' reflector portions removed to show fused meat portion. Core appears worse than it really is—whitish deposits are not result of excursion, but oxides of NaK that are normally deposited in routine removal of a core from NaK coolant

On November 29, 1955, at AEC's reactor testing station near Arco, Idaho, the world's first fast breeder reactor, EBR-I, was undergoing the last series of experiments scheduled at that time. Object of these difficult tests was to measure transient temperature coefficients, by measuring changes in reactivity of the reactor as the temperature of the fuel elements was increased. The reactor was placed on a short positive period and the fuel temperature permitted to rise to 500–600° C. To obtain the temperature coefficient of the fuel only, the liquid NaK coolant flow had to be shut off—so that the machine was actually operating not as a reactor at all but rather as a critical assembly. (The core pot was filled with NaK, but it was static.) On the last test in the series of deliberate power surges, the scientist in charge, watching special fast-acting neutron and temperature recorders and realizing a runaway was imminent, gave verbal instructions to the operating technician for immediate shutdown. The technician misunderstood and pressed the button activating the normal motor-driven shut-off rods. The scientist reached over and pushed the scram button. The interval, a delay of at most two seconds, was enough to permit power to overshoot to a level where the fuel rods melted down, some uranium alloying with core steel.

NUCLEONICS herewith presents the first photographs of the melted core after its removal from the reactor tank —a difficult and time-consuming operation that had to be carried out by remote control in a nitrogen atmosphere under a specially-constructed coffin.

The core had been the second to be used in EBR-I. A third core is now being designed and fabricated, and it is hoped to have the reactor back in operation by Fall.

Figure at top right (cover photograph) shows the bottom of the core, in which the U^{235}-containing reflector portion of the fuel elements (nearest the camera) are still undamaged. Further upward can be seen the portion containing active fuel—U^{235}—which melted and apparently formed iron-uranium alloy. At upper left in the melted region may be seen fuel thermocouple leads. Remnants of the fuel elements may be distinguished in the solidified mass at rear. The whitish encrustation on the reflector elements and on the surface of the melted mass are oxides of sodium and potassium from the NaK coolant.

One possibly encouraging thing that remains to be verified has to do with this last phenomenon. The core underwent a significant decrease in density due to boiling and volatilization of the NaK, and thereby became less reactive, from the nuclear point of view. It has yet to be established whether this took place an instant before or an instant after the meltdown. If the former, it would mean this phenomenon was operating as an added safety factor.

Fabricating and Testing Tubular Fuel Elements

By SAMUEL STORCHHEIM
Nuclear Division
The Glenn L. Martin Co.
Baltimore, Maryland

We plan to build a heterogeneous-reactor mobile-power package similar to the one shown in Fig. 1, and are developing thin-walled small-diameter tubular fuel elements for it. As shown in Fig. 2, such elements have a large surface area that aids heat removal. But fabrication procedures are complicated. A variety of problems face us in developing these fuel elements.

It has been calculated that by using these tubular elements in reactors now operating with flat-plate elements (such as the Materials Testing Reactor) a gain of 50% in heat production might be obtained. To develop means of fabricating and testing such fuel elements intensive research is necessary.

We plan to make our fuel elements of stainless steel with a core containing 20–30 wt % of fully enriched UO_2. We are also developing an element of almost the same geometry, but with aluminum substituted for the stainless steel. The wall thickness of these fuel elements, including fuel and inner and outer cladding, is only 30 mils.

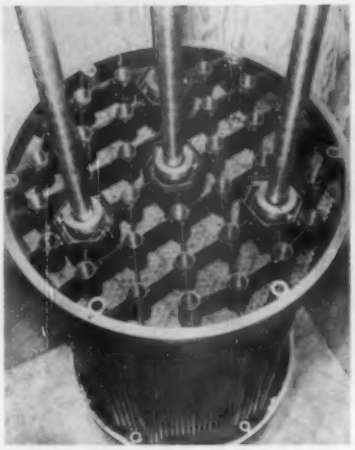

FIG. 1. View looking down into dummy core used to test hydraulic performance of thin-walled small-diameter tubular fuel elements; 1,500 of these tubes are visible under grid (circles connected by diagonals). Hexagonal openings are for control rods extending upward from core

FIG. 2. Bundle of tubular fuel elements. Each element is 25.5 in. long, of which 23 in. is active. Active section o.d. is 0.375 in.; central hole diameter is 0.315; walls are 0.005 in. thick, leaving 0.020 in. for "meat." End pieces have 0.485-in. o.d.

Dispersion of UO_2

A major problem is that of getting a proper distribution of UO_2 particles within the core tube; see Figs. 3 and 4. Since UO_2 has a density of about 10.9 gm/cm³ while Al has a density of only 2.7 gm/cm³, it is difficult to mix powders of such widely divergent densities. Fortunately, mixing UO_2 and stainless-steel powder is not as difficult because the density of stainless steel is 7.9 gm/cm³.

However, other problems arise. Since stainless-steel powders flow very freely, during the mixing process, or even in standing, the UO_2 particles might settle down through the matrix powder. Still, powder-metallurgy techniques that assure better distribution of dispersions can be used. These include use of the optimum combination of a number of characteristics, including: flow rates, particle sizes, particle distribution, particle shape, elements or alloy powders, additives to the powder, mixing times, weights of charge being mixed, and others.

Forming a Tube

After mixing, the powders must be consolidated into a core tube. A variety of methods are available for fabricating tubular products, including drawing, rolling, extrusion, rolling of sheet and then cold-roll forming, and the powder-metallurgy approach (*1*).

Stringering of UO_2. Fig. 5 shows how the UO_2 stringers out and the distribution becomes nonuniform during the cold fabrication of core materials containing UO_2 particles (*2*). This is a serious problem because the areas immediately surrounding the UO_2 particles are subject to radiation damage that permanently alters the matrix—stringering of the UO_2 concentrates these damage areas so that serious damage occurs. While the fuel elements are in the reactor damage can build up, and blisters develop, rupture, and allow the UO_2 to be exposed to the coolant. Once the clad is ruptured, fission products escape into the reactor coolant.

However, if the UO_2 particles are kept to a proper size and well distributed from each other, as shown in Fig. 6, the matrix areas that are damaged are isolated so that these regions do not interconnect (*3*).

Thus, a number of cold-working methods that normally would be employed in fabricating tubing can not be used in making fuel elements. But, as shown in Fig. 6, hot working eliminates the stringering effect. Since hot-working processes are more complicated and expensive than cold-working techniques, fuel-element core fabrication is quite complex and costly.

Cladding

Once the fuel-element core has been made, it must be clad on both surfaces and on its ends. The clad protects the core from the corrosive effect of the coolant and keeps fission products from the core out of the coolant. Absolute metallurgical bonding over the entire contacting surface areas of core to clad promotes the best possible thermal conductivity between core and clad. This is done to avoid areas where poor thermal conductivity could cause blistering and rupture of the clad.

We used direct bonding, in which the cladding material is bonded directly to the core. The alternate method (not used) involves placing an intermediate metal on the core or on the clads such that it bonds them. These intermediate metals can be used not only to facilitate bonding but also can be used as a barrier to excessive interaction between the core and clad.

There are a number of methods for bonding the clad to core. These include: furnace diffusion, cold-pressure welding, hot-pressure welding, liquid-phase welding, brazing, and others.

Furnace diffusion. The core material is assembled with the inner and outer clads and is placed in a furnace. While at temperature, the three components diffuse into each other and

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FIG. 3. Nonuniformity of dispersion results when −200 +325 mesh stainless-steel particles are dispersed in −100 +200 mesh aluminum starting matrix powder (sample unetched; magnification = 4×)

bond metallurgically to become an integral unit. Usually, this is accomplished more readily by using an intermediate metal between any two interfaces to be bonded. The reason for this is that self-diffusion of the same materials is much slower than the inter-diffusion of different metals or alloys.

Cold-pressure welding. Components are pressed together at room or slightly elevated temperatures. Usually, the temperature involved is below the recrystallization point of the metal components. For sufficient bonding to be attained by this technique, considerable plastic deformation is required, as well as exceptionally clean mating surfaces. Because of these sometimes excessive considerations, this technique normally is not used.

Liquid-phase welding and brazing. The components are assembled so that during subsequent heating a liquid phase develops at the mating interfaces. This normally is achieved by placing a low-melting-point material between the components to be bonded. When melted, the liquid phase cleans, flows, and metallurgically bonds the surfaces with which it is in contact. This technique can have several limitations, including the fact that during cooling the liquid-phase area solidifies, is stressed considerably, and cracks, or, the liquid phase reacts with the cladding or core material to an excessive degree and might penetrate the clad.

FIG. 4. Improvement of dispersion results when −200 +325 mesh stainless-steel particles are dispersed in −325 mesh aluminum starting matrix powder (sample unetched; magnification = 4×)

Hot-pressure welding. One method that has received considerable attention and shows excellent promise is that of hot-pressure bonding. Systems investigated include: Al-Ni, Al-Cu, and Al-Zr (*4*, *5*). The generalized curves of Fig. 7 indicate hot-press-bonding's capabilities. For example, increasing the pressure raises the bond strengths to high values. This is particularly true of the Al-Ni system, where increasing the pressure inhibits formation of a very brittle intermetallic zone, as shown in Fig. 8, and almost quadruples the bond strength. The same result is not observed with the Al-Zr or Al-Cu systems. Pressure has almost no effect on the zone thickness in the Al-Cu system (*6*). However, bond strength increases with greater pressure application.

Temperature effect. In a number of instances, higher temperatures yield better bond strengths; again see Fig. 7. But bond strength usually drops off because brittle intermetallic zones form and their strength decreases with increasing thickness. In some instances, after the decline the strength goes up with increasing temperature. The Al-Fe system does this and the rise is attributed to a phase change (*7*).

Time effect. Naturally, time always plays an important part in the bonding process, as seen in Fig. 7. But its effect generally is not quite as critical as that of temperature or pressure. Usually, with the formation of brittle

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intermetallic zones, strength does tend to drop off with excessive holding times.

Cleanliness. In bonding work it is extremely important to clean the surfaces to be bonded properly. It also is important to complete the bonding process as quickly as possible after cleaning. Standing in air can contaminate the freshly cleaned surfaces so that they will be inhibited from bonding to each other.

Bonding dies. One of the chief limitations of this bonding process until recently has been the fact that the bonding dies have not been able to withstand high pressures at temperature. In the beginning, it was found that 18-4-1 tool steel performed satisfactorily at 600° C and 12 tsi (tons per square inch). Later, Inconel X was used; it extended the temperature up to 650° C and allowed pressure to be increased to 15 tsi.

New developments in the field of molybdenum alloys add to the potentialities of high-temperature high-pressure bonding. The moly alloy containing 0.5% titanium looks particularly promising; work has been conducted as high as 900° C, 5 tsi with little to no effect upon the die material.

Of course, graphite dies are available for very high temperature work. But they are limited in that they normally can not take pressures above 2–3 tsi; also, they might not provide the proper protective atmosphere. Almost universally the best atmosphere to work in when attempting to bond two metals is no atmosphere—high vacuum.

Nondestructive Testing

Once a fuel element is fabricated it must be tested for conformance to specifications. Among nondestructive tests that can be used are those employing principles of: ultrasonics, eddy currents, zyglo, magnetism, heat transfer, radiography, or corrosion.

Ultrasonic test. When high-frequency sound waves are directed at or through a specimen, the reflection or transmission of the sound energy is seen on an oscilloscope. Discontinuities in the specimen change the pattern seen on the oscilloscope. Defects are evaluated by comparing the test pattern with patterns produced by specimens having known defects. Although ultrasonic testing is useful for determining internal uniformity of a material, and also for testing the bonding of various materials, its adaptation for use with small-diameter thin-walled tubular elements is incomplete.

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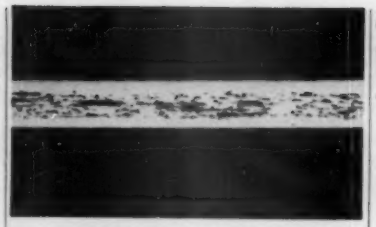

FIG. 5. Oxide particles stringered out during cold-work fabrication (magnification = 6×)

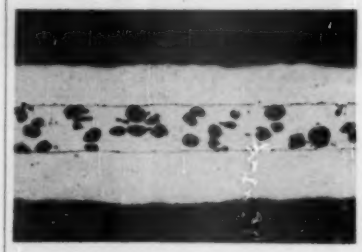

FIG. 6. Hot-working keeps oxide in discrete particles, no stringering (magnification = 25×)

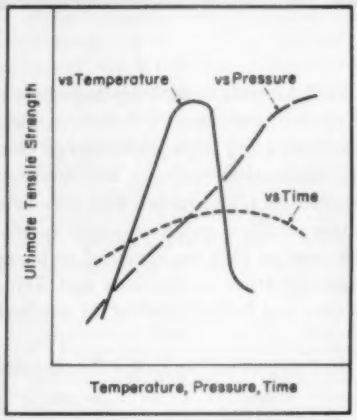

FIG. 7. General curves showing how temperature, pressure, and time affect bond strength of two metals that form brittle interalloy zones during interaction

Eddy-current test. When a coil carrying an alternating current is brought near a conducting specimen eddy currents are induced. These eddy currents produce a magnetic field that opposes the original magnetic field. The impedances of the exciting coils or pick-up coils near the element are affected by the eddy currents in the metal specimen. Thus, if a defect in the sample distorts the path of the eddy currents, the apparent impedance of the coil is changed, and defects in the specimen are revealed. The eddy current test is exceptionally efficient in rejecting tubes with very small discontinuities (of 1–2 mils in diameter).

Zyglo test. The specimens are im-

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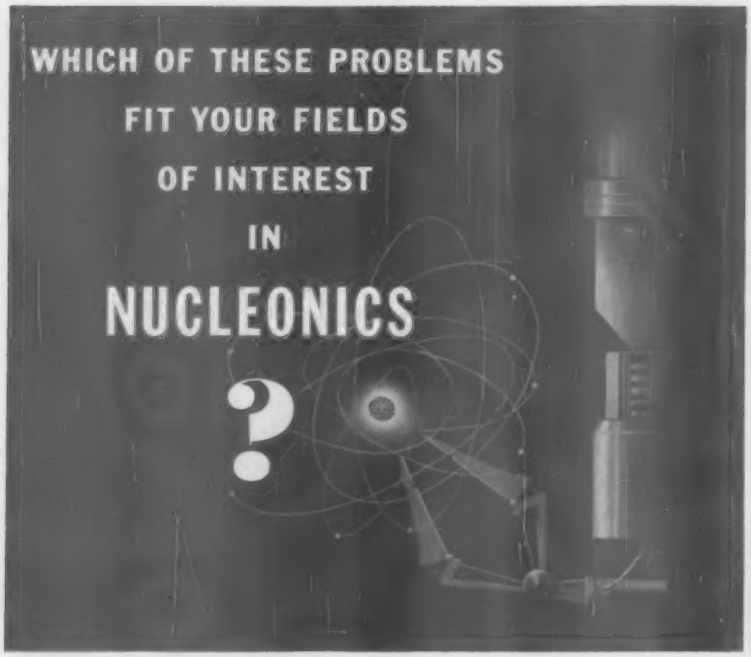

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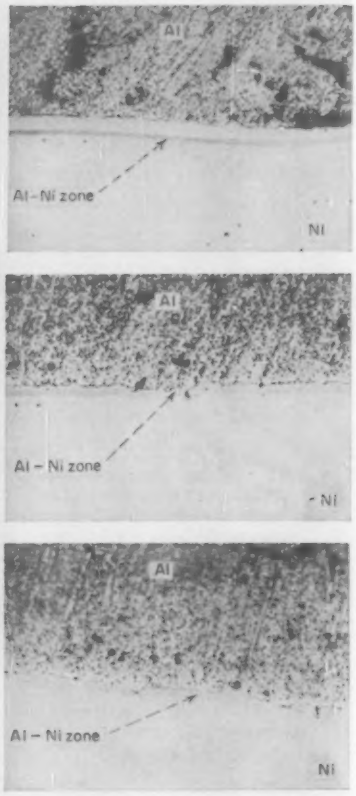

FIG. 8. Formation of very brittle intermetallic zone between aluminum and nickel is inhibited by increasing hot pressure (from top to bottom; magnification = 500×)

mersed in an oil that penetrates any cracks or fissures, and the surface oil is washed off; the only oil left is in the fissures. If the sample is placed in a developing powder that reacts with the oil in the cracks, ultraviolet light causes the developer in the cracks to fluoresce and the surface cracks are seen readily. Zyglo testing is an old standby for checking surface cracks.

Magnetic test. When a ferromagnetic material is placed in an electromagnetic field, magnetic lines of flux form patterns about the specimen. Any defects in the specimen offer points of flux leakage, which are outlined by covering the specimen with a solution containing finely divided ferromagnetic particles, such as iron oxide. Magnetic techniques are excellent for testing fuel elements containing ferromagnetic materials.

Heat-transfer test. If portions of a specimen remain unbonded, heat transfer through these areas is inhibited and a localized hot spot exists. If a substance is applied that has a melting

point such that a hot spot causes melting at the defective area, it would be relatively simple to spot. This is a sensitive technique that might have considerable test value with tubular walls. Even more useful might be an infrared camera such as Baird's Evaporgraph.

Radiography. Radiography is a fine method for determining distribution of the oxide or any gross imperfections in a fuel element. With the uranium within a fuel element continually emanating rays that leave an impression on film, autoradiography could be a very fine technique for pinpointing oxide distribution within the core.

Corrosion test. This technique can determine whether or not fabrication processes have yielded fuel elements that can be safely inserted in a reactor. Included in corrosion testing are boiling-water tests, autoclave tests, actual loop tests, as well as in-pile tests. Boiling-water and autoclave tests can be used as "go, no-go" specifications; a fuel element that has passed all other nondestructive tests is autoclaved to determine whether the clad is leaktight. Loop tests are valuable in determining the effect of pile conditions other than irradiation, such as erosion. But an in-pile test gives the most conclusive data.

Destructive Testing

Conventional tube tests, including flare tests, crush tests, bend tests, and hydrostatic-pressure tests, worked out over many years in the tube-fabrication field can be used. Other methods include: peel tests, thermal shock, mechanical shock, and metallography.

Peel test. An attempt is made to strip the clad from the core so as to evaluate roughly the bond. This crude but effective method gives a rapid qualitative evaluation of a core-to-clad bond. It is limited in that no quantitative information is obtained; it cannot distinguish intermediate bond strengths readily. It can only be said that the bond is either poor, good, or excellent.

Thermal-shock test. The specimen is raised to a relatively high temperature and plunged into cold water, and thus shocked. Poor bonding can manifest itself in a number of ways including blistering or clad growth. Occasionally, this test is limited when unbonding takes place without sufficient distortion for visual observation. When this occurs it is necessary to combine this destructive test with a nondestructive method of evaluation of the damage done.

Mechanical-shock test. The fuel element is impacted violently over localized areas that then are checked by thermal shock, peel testing, microscopic evaluation, etc. This test is limited to evaluation by other tests; results immediately after the mechanical shock cannot be evaluated unless the specimen is tested destructively by peel, thermal, or micro testing.

Metallography test. Microscopic evaluation can be used for intimate study of the metallurgical nature of the bond attained between the clad and core. Oxide distribution in the matrix can be determined, and any gross imperfections are apparent. In addition metallography is used for measurements of the clad-core thicknesses. It also helps to determine uniformity and concentricity of the core and clad.

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Burst-Slug Cerenkov Detector

By C. M. GORDON and J. I. HOOVER

Nucleonics Division, Naval Research Laboratory, Washington, D. C.

A possible method for detecting leakage of fission products into a reactor water-cooling system depends on detection of the high-energy electrons from a few selected fission products using a Cerenkov (*1*) counter. Preliminary results show sufficient promise to warrant a discussion.

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ation) as long as its velocity (v) is greater than the speed of light (c/n) in the medium. Assuming v/c equal to one for the betas of interest, the Cerenkov radiation intensity will be proportional to the range and consequently the energy of the electron.

If water containing beta-emitting isotopes of different energies is viewed by a photomultiplier tube, pulses are produced that are proportional to the Cerenkov radiation emitted. By setting a discriminator so that only pulses produced by electrons with energies of 5 Mev or greater are passed, the high-energy electrons can be separated from both the low-energy electrons and the phototube noise.

The maximum beta-particle energy of most isotopes is <5 Mev. This includes isotopes formed in fission and in neutron activation of water contaminants and corrosion products. There are, however, a few fission products of relatively short half-life with beta energy end-points >5 Mev. These are listed in the table.

Equipment and Procedure

In an attempt to identify the half-lives listed in the table, experiments were conducted with water containing fission products produced by photofission* of natural uranium. Uranium nitrate solution was bombarded in a betatron beam at ~20 Mev. The solution (slightly yellow in color) was then transferred to a container mounted on top of a 6292 DuMont photomultiplier.

The signal from the photomultiplier was fed to an amplifier, discriminator and scaler. The discriminator was set to eliminate noise from the phototube and pulses due to electrons of <4–4.5 Mev energy.

The counting rate was taken as a function of time and the gross counting rate curve analyzed into its component half-lives. In general, the experimental counting rates were ~10,000 cpm initially. Decay was followed until the rate was ~100 cpm.

It should be pointed out that the counting was done in the presence of all the fission-product activity. The other fission products add a background flux of ~30 mr/hr at the container preceding the run. This radiation field had no noticeable effect on the shape of the decay curves. This indicates that at least this order of background fluxes is tolerable.

Experimental Half-Lives

Analysis of several sets of data revealed the presence of the half-lives listed in column 6 of the table. It can be seen that the observed half-lives agree fairly well with those expected from the known isotopes emitting beta particles of >5 Mev energy.

Chemical separations were made of iodine and yttrium and their half-lives observed with the Cerenkov counter. The measured half-life of the chemically separated iodine was 86 sec; that of the chemically separated yttrium was 17 min—both in agreement with published values (2) as given in the table.

Sources of Error

The uncertainties in observed half-lives listed in the table are due to several reasons. The production of fission products by photofission is extremely inefficient, consequently large samples of uranium (several grams) had to be bombarded. Because of the large samples, which discolored the solution, the Cerenkov radiation was strongly absorbed, leading to decreased pulse heights. Also, the quantity of fission products formed was small, leading to low counting rates and consequently poor statistics, especially with the longer half-lives. In the analysis of the curves the poor statistics did not permit the half-lives to be determined with great accuracy.

* The photofission process was the only means available to produce these short-lived isotopes.

High Energy Beta Emitters Formed in Fission

Isotope	*Half-life*	*Photofission yield (%)*	*Betas per disintegration (%)*	*Beta end-point (Mev)*	*Observed half-life*
Br^{87}	55.6 sec	1.9	30	8.0	~50 sec
I^{136}	86.0 sec	2.9	100	6.4	~95 sec
Rb^{90}	2.7 min	3.3	100	5.7	~2.5 min
Y^{94}	16.5 min	4.8	100	5.4	~21 min
$Kr^{88} \rightarrow Rb^{88}$	2.77 hrs	2.6	78	5.3	~2.9 hrs

An additional contribution to the lack of precision was the discriminator setting. In order to accept a reasonable fraction of the beta spectrum the discriminator was set at ~4–4.5 Mev. This setting allowed some contribution from isotopes with beta end-point energies <5 Mev. These contributions, although not intense, conceivably introduced changes in the observed half-lives, although they themselves were not resolved. Thus Br^{84} with a 30-min half-life and an end-point of 4.68 Mev could have lengenthed the 17-min yttrium half-life to the observed 21 min. The contribution of the Br^{84} should be small since its yield in photofission is ~1% and only 40% of the disintegrations go by way of the 4.68 Mev beta.

We plan to repeat these experiments using the Naval Research Laboratory reactor to produce neutron fission products, and a phototube with a higher transmission in the ultra violet. With these improvements and a higher discriminator setting, the half-lives should be resolved easily. We also plan to make chemical separations to make the identifications less ambiguous.

Advantages of Method

A fission product detector of the type described has the following advantages: The reactor coolant (water) can be used as the detecting medium. It should not be necessary to perform chemical separations to detect fission-product leaks. High backgrounds of both betas and gammas can be tolerated. A choice of half-lives is available upon which to base the detection system. The detector is independent of the type of fuel element rupture, i.e. small cracks should be detected since the $Kr^{88} \rightarrow Rb^{88}$ chain, having a long half-life (2.8 hrs), would have ample time to diffuse into the water without being seriously depleted by decay. The fission products considered have high yields which should lead to a relatively high sensitivity. Measurements would be sensitive to the holdup time of N^{16}, however this is not considered a disadvantage since the 10 Mev beta from the decay of N^{16} could be used as a calibration and check point.

* * *

The authors wish to express their appreciation to Dr. John McElhinney for making the betatron available for the sample irradiation.

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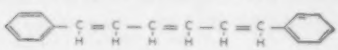

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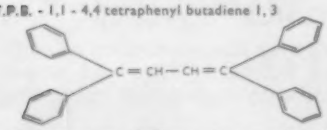

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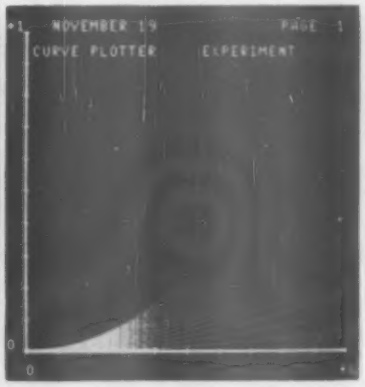
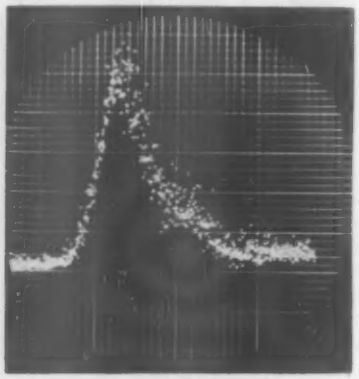
TECHNICAL ADVANCES

The Things They Do With CRT Displays

As is attested by the two examples given below, nuclear applications have led to ever-increasing sophistication of oscilloscopic displays almost as much as have applications lying in the fields of radar and military systems.



Plotting computer output



Sampling to see 10^{-9}-sec pulses

Curve plotter. At ORNL R. J. Klein has designed a cathode-ray-tube readout for the Oracle which plots curves and legends in a display like that shown on the left above. The unit can also prepare lettered displays similar to printed pages. The device not only impresses visitors, it is 5,000 times faster than hand plotting, turning out a complete graph with axes and labeling in less than 1 sec. Lettering is semiautomatic with a maximum speed of 2,000 letters/sec. The linearity of the graphs is within 1%, and most of this error is caused by crt nonlinearities.

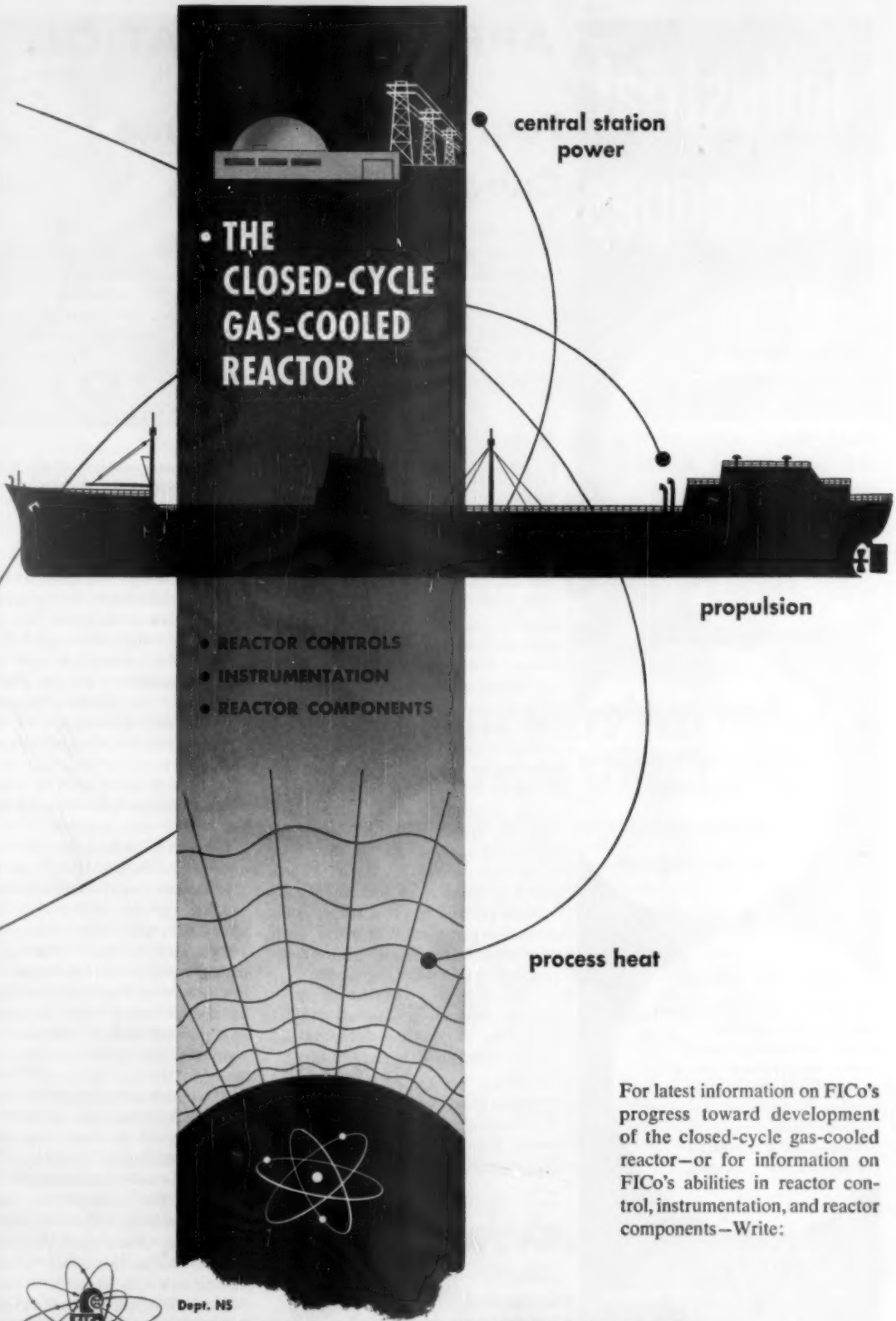
Sampling oscilloscope. R. M. Sugarman at Brookhaven National Laboratory has built an oscilloscope for pulses in submillimicrosecond region. It is based upon an idea that has been discussed before (see I. A. D. Lewis and F. H. Wells "Millimicrosecond Pulse Techniques," p. 208, McGraw-Hill Book Co., New York, 1954). Here's what is done: the amplitude of similar repetitive pulses are sampled at successive point in the waveform, the points being chosen by sampling at times delayed with respect to the start of the pulse by ever-greater delays. The resulting samples are stretched and displayed on a conventional oscilloscope whose horizontal deflection is linearly related to the sample time delay. The point is that just as it is easier to build a fast coincidence circuit than a fast amplifier it is easier to build the sampler rather than an ultrafast scope. Typical result is shown in the figure on the right above, obtained with Co^{60} gamma rays and a terphenyl plus toluene scintillator whose decay time is 2.2×10^{-9} sec. Time scale is 5×10^{-9} sec per 10 small divisions.

ZPR-5: Two-Region Critical Assembly

The three Argonne talks on their "fast-slow reactor" principle were among the most novel discussions at the recent American Nuclear Society meeting in Washington. Fred H. Martens gave a general description of ZPR-5, the new two-region critical assembly at Argonne (NU, Dec. '56, p. R7), and G. J. Fischer spoke on experimental results obtained since the machine was first started up Aug. 30, while Robert Avery described a design for a power breeder using the coupled fast-thermal principle.

It's interesting that the idea of coupling fast and slow systems is rather old (see J. R. Menke, Interim note on mixed pile studies. MONP 412, 1947). However there appears to have been no serious investigation of the coupled fast-thermal concept for a practical power breeder system.

Avery's aim is to see whether or not a two-region reactor would be a practical power-producing machine. Incentive is that the system has the kinetics of a thermal reactor and, it is hoped, the breeding properties of a fast, plus a much lower fuel inventory than a full fast unit. Another advantage, according to Avery, is much longer neutron lifetimes.



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APPLIED RADIATION

Four Simple, Versatile Cobalt-60 Facilities

Gamma-irradiation facilities are increasing in number at an increasing rate. Here are four interesting designs for Co^{60} installations. The large B. F. Goodrich lead-pig design has been in operation for more than a year without difficulties. It contains a total activity of 1,400 curies. The two designs for smaller sources are from Chalk River. Newest is the swimming-pool facility recently put into operation at Rensselaer Polytechnic Institute, Troy, N. Y. This has a 970-curie hollow cylindrical source.

1. Goodrich Facility

By R. G. BAUMAN
B. F. Goodrich Research Center
Brecksville, Ohio

Flexibility of operation was the governing consideration in our choice of a lead-pig facility. We envision research projects ranging through radiation-damage tests, elevated-pressure polymerization, and continuous-stream organic reactions on a small pilot scale.

We considered and rejected the swimming-pool and cave types as less suited to our purposes. The swimming pool with its advantages of low cost, visible operation, and considerable flexibility appeared difficult to use for pilot-plant operation. The cave type is the most flexible, has almost no volume limitations, and with the source shielded permits entry to set up complicated experiments. However, such a facility is expensive, and pilot operations must penetrate thick shielding walls if part of the plant is to be approached during operation.

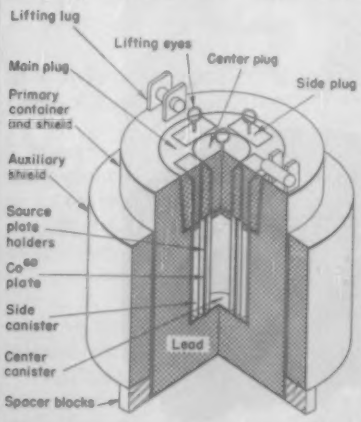

FIG. 1. Isometric view of Goodrich pig shows positions of 4 cobalt plates and 5 irradiation volumes

Pig Design

Our pig design was based on the following criteria: safety, maximum irradiation volume in several spaces, weight limit of 5 tons, operational flexibility, uniform flux, reliability, and readily changed sources. The weight limit was set by the handling capacity at Brookhaven. By operational flexibility we mean the availability of high and low temperatures, high-pressure stirring, and the like. The desire for uniform flux must be balanced against the need for large volumes.

Figure 1 is an isometric view of the pig designed for us by the Walter Kidde Nuclear Laboratories and approved by our design group. The four flat aluminum-clad plates have dimensions of $14 \times 2.25 \times 0.312$ in. The use of flat plates considerably increases design flexibility over the limitations imposed by the restricted inner diameters of conventional hollow cylinders. Ours were the first plate-type sources released by the AEC to private industry.

The plates are tangent to a 7-in. circle with their long axes vertical. This separation was the largest possible under the total-weight limitation. There results a 6-in.-diameter central working volume. The sources are held in frame-type holders that slide into slots in the body of the pig. This arrangement allows easy removal. If a source having new dimensions is to be used, it can be inexpensively added by making a new frame holder without expensive alterations in the pig body. The loading of these frame holders into the

FIG. 2. The pig in place. Shield projecting above the top is to protect personnel on overhanging balcony when plugs are removed

pig was done under 14 feet of water at Brookhaven.

In order to maximize the efficiency of utilization of the radiation from the plates, a 2⅛ × 3½-in. rectangular radiation volume is located behind each. Thus there are five separate radiation chambers, enabling five scientists to use the facility simultaneously. The entire pig in its final location is shown in Fig. 2.

For loading purposes there is a main plug covering the actual sources. In it are a central plug and five side plugs giving access to each of the radiation chambers. The plugs contain lifting eyes and are held in place by sliding-bolt-and-lock arrangements. Passing through each of the plugs are three helical tubes, threaded at both ends, to give access to the radiation chambers for plumbing attachments, thermocouples, etc. To the bottom of each plug is attached a can for the sample.

Operation

The plugs are removed from the pig by a hydraulic lift equipped with a fastening head that can be locked to any of the plugs with a bolt and cotter pin. The lift is attached to a swinging boom that moves the plug and its attached can to the side for safe loading. Each chamber is equipped with a separate key lock available only to the scientists using it.

A wooden mock-up of the top of the pig is available within the circumference of swing of the plug hoist. This mock-up is employed to check experi-

(above) Nuclear-Chicago scintillation detector is lowered into water for tracing the radioactive sewage effluent at varied depths over a 25 square mile area. (right) Gamma-ray spectrometer system, ratemeter and recorder on laboratory ship measure and chart traces of radioactive scandium during 36-hour period of experiment.

RADIOACTIVITY HELPS PREVENT BEACH POLLUTION FROM SEWAGE EFFLUENT

In a unique experiment just completed in Santa Monica Bay, California, radioactive isotopes were successfully used to trace the dispersion of sewage effluent in ocean waters. The results are helping to establish proper design procedures to insure against beach pollution in a current expansion of the Los Angeles sewage system.

The tracer experiment was a joint project of Hyperion Engineers, Nuclear Science and Engineering Corporation and the Hancock Foundation of the University of Southern California. Twenty curies of scandium-46 were mixed with sewage effluent and discharged into the sea. Scientists aboard a laboratory ship then took radioactive measurements over a wide area to determine dilution rate and direction of diffusion.

Since this was a "one-shot" experiment, the dependability and overall sensitivity of the equipment were extremely important. The instruments chosen, including the DS5-3 scintillation detector, 1810 gamma-ray spectrometer, 181 scaler and 1620 ratemeter were standard Nuclear-Chicago catalog items.

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FIG. 3. This area holds the gamma facility and its wooden mockup, which appears at the left

mental setups before running them in the pig. Figure 3 shows its position.

Flux Distribution

The radiation flux in each can has been measured with glass-slide dosimetry (*1*). In the central can the flux has a maximum of 1.2×10^5 r/hr. It is uniform within 10 per cent over a cylinder 2½ in. in diameter and 7 in. high. In the side chambers a rectangular volume 0.2-in. thick and 11.7-in. high, parallel to the source plates, varies only 10 per cent in flux.

Safety

The sources are shielded by over 10 in. of lead in all directions. To escape weight limitations the side chambers were filled with lead plugs during shipment. After permanent location at the research center, an outer shield adding 3 in. of lead was placed around the pig, and shipping plugs were removed. The maximum external exposure dose at the outer shield is 1.75 mr/hr. The large useful opening to the central irradiation volume allows a wide-angle cone of radiation to emerge from the top of the pig when the plug is removed. To protect personnel on upper balconies to one side of the pig, a top shield is provided to collimate the emergent beam (Fig. 2).

The entire area containing the gamma facilities, shown in Fig. 3, is surrounded by a 4-ft-high concrete-block wall to deter unauthorized personnel from entering. When opening

and closing the pig, the operator is accompanied by a trained staff member who supervises the operation from a health-and-safety point of view. This supervisor is equipped with a safety check list of all opening and closing operations.

The radiation facility is constantly monitored, and when the radiation flux rises to a value unsafe for continuous occupancy of the overhanging balconies, red lights flash on the balconies and at the pig, and a warning buzzer sounds. The monitor unit is checked for safe operation before opening the pig. The roof area directly above the pig is closed to all personnel.

The maximum flux external to the pig with the central plug open has been carefully measured as a portion of the radiation safety program. The flux was measured with a Jordan Radector radiation meter suspended from an overhead crane and read through binoculars. The flux fields are notable for a minimum at the pig's axis. This is doubtless due to self-shielding as the axis is approached. The effect of the balcony shield is clearly evident. For example, at a point 20 ft above the pig and 10 ft from its axis (the approximate location of the upper balcony) the shield reduces the flux from 1.8 r/hr to 0.12 r/hr.

* * *

I am indebted to H. Neff, C. Stockman, J. Born, and D. Harmon of the B. F. Goodrich Nuclear Developments Group, for their assistance in the preparation of this paper. G. Lowe of the B. F. Goodrich design group and J. Byrnes of the Walter Kidde Nuclear Laboratory were responsible for the pig design. Also I am indebted to O. Kuhl and B. Manowits of Brookhaven National Laboratory for their invaluable advice during the design and loading of the gamma facility.

BIBLIOGRAPHY

1. R. G. Bauman, NUCLEONICS **14**, No. 6, 90 (1956)

2. Rensselaer Pool

Newest of the Co^{60} pool facilities is the one at Rensselaer Polytechnic Institute with a 970-curie hollow cylindrical source. The pool is 14 ft deep with a 6 × 8-ft cross section. Additional shielding is provided by solid rock in which the pool is built.

A total of 26 irradiation spaces are provided in the brass source holder. They consist of open cylinders that project down from the top surface of the holder into the air-filled volume surrounding the source. Samples are irradiated by placing them in cans and

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pushing them down into one of the spaces to force out the water that fills them in the absence of a sample. One space is in the center of the cobalt pipe, which is 13 in. long and 2 in. in diameter. Four of the others will take 8-in. diameter cylinders; four take cylinders of 5-in. diameter; 17 take cylinders of 3-in. diameter.

A 17-ft shaft extends below the bottom of the pool. The cobalt can be lowered into this shaft when work is to be done in the pool.

3, 4. Two Small Cobalt Facilities*

By P. B. AITKEN, P. J. DYNE, and E. C. TRAPP
Atomic Energy of Canada, Ltd.
Chalk River, Ontario

Two simple Co^{60} irradiation facilities have been in use in the Chalk River research chemistry laboratories for some time. The first is a cave-type facility employing a single 100-curie source. The second uses six 30-curie sources in a 1½-in.-diameter ring to provide a highly uniform field of about 4,000 r/hr.

100-Curie Source

The single-source device makes use of an existing storage hole in the floor of the laboratory, 6 in. in diameter and 8 ft deep. The source travels up and down a tube of about 1½-in. diameter (Fig. 1). The tube passes through staggered holes in three lead plugs located at intervals in the hole. Thus when the source is at the bottom, no radiation can be detected at the floor level. Compressed air propels the source to the top of the tube and a pin holds it there. It falls by its own weight when the pin is removed. The top of the tube is capped, and a small hole allows air to escape. Samples to be irradiated are placed around the capped end and surrounded by portable shielding.

Some difficulty was encountered in making bends in the tube without flattening. This was overcome by making

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* Contribution from the Engineering Development Branch and the Research Chemistry Branch, Atomic Energy of Canada Limited, Chalk River, Ontario. Issued as A.E.C.L. No. 383.

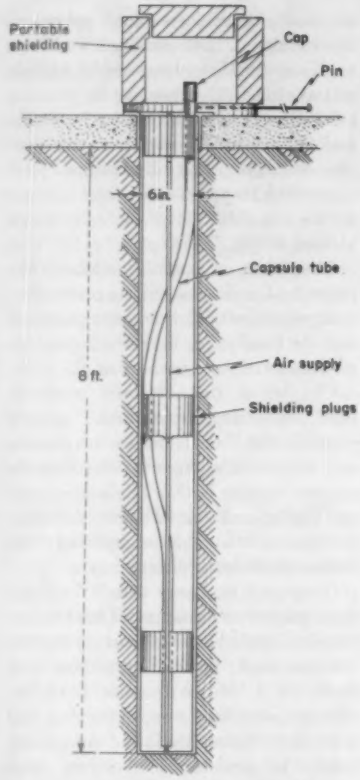

FIG. 1. Shielding arrangements for single 100-curie Co^{60} source. Compressed air blows source up from storage position at bottom of tube. The pin holds it in place

a simple wooden mandrel bender for this purpose. The source is loaded from a container called a "castle" with a gate in its bottom. This is placed over the tube with the cap removed. The system is unloaded by blowing the source back into its castle.

The principle merit of this device is the freedom one has in the arrangement of apparatus around the source. The shielding can be rebuilt to suit each experiment. Its drawback is the rapid variation in field with distance that is inevitable with a single source.

Ring-of-Six Source

The second facility was designed for six sources in the form of aluminum capsules, each containing about 30 curies. The sources form a ring around the sample (Fig. 2). This arrangement gives a high uniform radiation flux over a cylindrical volume of 1½-in. diameter and 1½-in. height—the height of the sources.

The lead shielding consists of three rings placed one on top of another. The inside diameter of the middle ring is larger than that of the upper and lower rings, and the sources are in the annular cavity formed by it. The vertical hole through the center of the rings is filled by a lead plug that is moved by a mechanism located beneath the shielding. Samples to be irradiated are placed on the top of the lead plug. Then the plug is lowered so that the sample is in the center of the ring of sources. Auxiliary shielding is placed on top to cut down radiation escaping upward when the plug is lowered.

The sources are located in short pieces of tube, open at both ends, which are attached to adjuster rods passing radially through the center shielding ring. The radiation flux is varied by moving the adjuster rods.

For loading sources each source-locating tube in turn is pushed to the central position, and a source is dropped in from a castle with a gate in its bottom, by means of a suitable guide tube. For unloading, the same procedure is followed, with the center plug removed so that the sources fall into a shipping castle placed underneath the shielding. In normal operation pins are placed in the adjuster rods to limit the source travel.

Our facility has a central hole diameter of 3 in., which can be reduced to 1½ in. with suitable sleeves. With 180 curies of Co^{60} we observe a maximum dose rate of about 4,200 r/hr. Shielding cost was about $1,000. The system requires a room with a floor capable of carrying large loads and an overhead hoist for moving the heavy pieces of lead. The device has proved to be serviceable, flexible, and adaptable to a wide variety of sample containers.

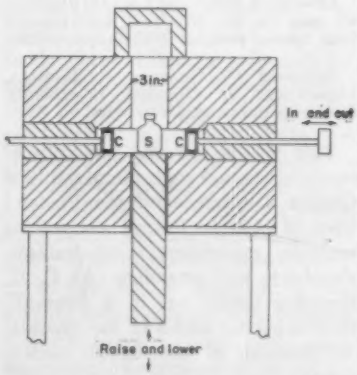

FIG. 2. Shielding arrangement for six 30-curie Co^{60} sources. Sources C are arranged concentrically around sample S and give an intense, uniform field

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BOOKS

Progress in Nuclear Energy. Series 2, Reactors, Vol. 1

Edited by R. A. CHARPIE, D. J. HUGHES, D. J. LITTLER, and M. TROCHERIS (McGraw-Hill Book Co., Inc., New York, and Pergamon Press, London, 1956, x + 492 pages, $14.00).

Reviewed by JAMES J. DUTTON, Nuclear Engineering Div., Bell Aircraft Corp., Buffalo, N. Y.

A compilation of reactor review papers presented at the 1955 Geneva Conference on the Peaceful Uses of Atomic Energy, this book compactly presents a great deal of technical design information of use to persons aiming to extend reactor technology. Comparison of data is facilitated by the presentation of review papers, together with a reactor catalog (including data to April 1956) and a number of tables.

Research reactors described include those in Canada, the United States, Russia, France, Sweden, Norway, and Britain. An appreciable amount of information on NRX features, experimentation, and operational experience is given by D. G. Hurst and A. G. Ward of Chalk River; they also briefly describe ZEEP and NRU. J. R. Huffman and A. M. Weinberg present a noteworthy comparison of the design and usefulness of the many research reactors in the United States—including MTR-type, D_2O, and water-boiler reactors.

D. I. Blokhintsev and S. M. Feinberg describe soviet research reactors, including the reactor in the Russian power station. APS-1 fuel-element details are lacking. This chapter also covers a reactor and early postwar research not described at Geneva; at the pre-Geneva nuclear session of the USSR Academy of Sciences, the Soviets told of their equivalent of the CP-1, which they claim to be the first nuclear reactor on the European continent.

European research reactors, and significant experimental work with them, are described by J. Gueron. F. W. Fenning details U. K. research reactors —GLEEP, BEPO, ZEPHYR, DIMPLE, PLUTO, and LIDO.

Power reactors described in the volume include: the PWR, Borax-3, aqueous homogeneous power reactors, British gas-cooled reactors, North American Aviation's sodium-graphite reactors, and fast reactors.

J. W. Simpson and Milton Shaw ably describe the reactor and plant of the pressurized-water reactor at Shippingport, touching on its major components, core design, materials, primary auxiliary systems, reactor control, plant container, and site facilities. Mechanical, thermal, and hydraulic considerations of the PWR core are presented by I. H. Mandil and N. J. Palladino. Useful design and operating experience acquired with the boiling-water Borax-3 reactor are detailed by J. R. Dietrich, H. V. Lichtenberger, and W. H. Zinn. Design features of aqueous homogeneous power reactors are covered by R. B. Briggs and J. A. Swartout.

In a brief chapter, Sir Christopher Hinton touches on graphite-moderated gas-cooled piles (Windscale and Calder Hall) and British nuclear power plans. Fortunately, the recent conference on British reactors has made more design information available.

Chauncey Starr describes the sodium reactor experiment in detail and touches on future prospects for the sodium graphite reactor concept. W. H. Zinn briefly reviews fast power reactors in discussing: plutonium-fueled reactors, breeding ratio, limiting radiation damage, high specific power, plant breeding performance, heat transfer with flux-flattening, reprocessing, control, and the advantages of spiking thermal reactors with fuel bred in fast reactors. A reactor catalog listing about 120 reactors completes the volume.

Progress in Nuclear Energy. Series 4, Technology and Engineering, Vol. 1

Edited by R. HURST and S. McLAIN (McGraw-Hill Book Co., Inc., New York, and Pergamon Press, London, 1956, xiii + 420 pages, $12.00).

Reviewed by CHARLES F. BONILLA, Department of Chemical Engineering, Columbia University, New York, N. Y.

This volume consists primarily of carefully selected papers from the 1955 Geneva Conference on the Peaceful Uses of Atomic Energy on reactor coolants, moderators, heat transfer, chemistry, and corrosion. As F. H. Spedding points out in a foreword, these are vital topics in the eventual development of economical nuclear power.

Chapter 1, on heavy water, starts off with Benedict's detailed coverage of the physical chemistry, design, and economics of the distillation, electrolysis, and chemical exchange processes. He concludes that distillation of ammonia-synthesis hydrogen is, at $43 per pound of D_2O, the cheapest by-product method. This is followed by Baertschi and Kuhn's brief description of a simple countercurrent distillation pilot plant with two packed-column sections of 1.8 cm HETP 2–3 ft high, which yielded 99.8% D_2O.

Chapter 2, on graphite, contains the paper by Currie *et al.* on the production and properties of U. S. reactor graphite, and the brief paper on French graphite manufacture, by Legendre *et al.*

Chapter 3, on beryllium oxide, is brief, containing Hutter and Pingard's paper on the French and Indian process and Meyerson's paper on the Russian process for pure BeO. The latter paper and Caillat and Pointud's paper outline the production of dense sintered BeO bodies of accurate dimensions.

Chapter 4, on liquid metals, includes three papers on liquid metal heat transfer—by Mikheyev *et al.*, surveying the Russian work; by Hall on sodium and NaK in a double-annulus heat exchanger; and by Lyon, surveying the published theoretical and empirical results in general. Hall shows that considerable circumferential variation of temperature can be expected due to any slight eccentricity. Also included is Barnes' paper describing liquid metal pumps.

In Chapter 5, on engineering, Boeschoten reports on work to improve the thermal contact between aluminum and uranium, pressure or liquid sodium being the only methods found. Ristic *et al.* show that thermal cycling above a certain power damages the thermal contact between a uranium rod and its aluminum can, due to plastic flow of the latter. Yvon describes the design of the Saclay fuel assembly, showing how the fuel rod and the annulus dimensions followed from the desired operating conditions.

There are two original sections in this chapter. G. W. K. Ford of Harwell discusses the principles of pump selection, referring specially to shaft seals, bearings, and gas blankets. Bearings lubricated with the seal gas are proposed for molten metal and salt pumps. H. A. Roberts discusses boiling types and mechanisms, and covers the principal correlations of heat-transfer coefficients, burn-out flux, density and circulation, and unstable flow.

Chapter 6, on reactor chemistry and corrosion, contains four papers on corrosion. Drayley's paper on aluminum

concludes that low-nickel alloys can be used in pure water up to the critical point. Thomas covers aqueous corrosion of zirconium. Addition to Sn counteracts the harmful effect of N_2 and improves the corrosion-product film; Zircaloy-2 has a very low corrosion rate up to the critical point. Epstein describes corrosion techniques and results for solid metals in liquid metals and describes the reaction and the solution mechanisms of corrosion, as well as other special aspects. A section summarizes Weeks' papers on the solubility of structural metals in molten bismuth. Nickel is leached out of Ni-bearing stainless steels and also decreases the solubility of U in Bi. The effects of Zr and other additives are also discussed.

In addition, Robertson presents a survey of theoretical and experimental work on the radiolysis of H_2O and of D_2O and a description of its extent in various reactors; this section is more general than was his conference paper. Rockwell and Cohen's paper on the water chemistry of the PWR discusses the problems (i.e. corrosion and crudding), methods of obtaining the desired data, and their application to reactor design. Radiation does not significantly increase corrosion if the corrosion product is adherent. Secoy gives the phase diagrams for aqueous solutions of the uranyl salts considered for aqueous homogeneous reactors. The kinetics of the peroxide problem are also discussed. Finally, Kitzes and Lyon cover the physical properties, sedimentation rates, corrosion, and pumping of UO_3 slurries in water at 250° C, concluding that these slurries are satisfactory for nuclear reactors.

In summary, this volume is a useful compilation of selected important Geneva papers, along with several new ones, on the general subject of coolant and moderator technology. It will be particularly useful to the worker in this field who does not have the corresponding Geneva volumes, in view of its greater handiness.

Medical Effects of the Atomic Bomb in Japan

Edited by A. W. OUGHTERSON and S. WARREN (McGraw-Hill Book Co., Inc., New York, 1956, xvi + 477 pages, $8.00).

Reviewed by ROBERT J. HASTERLIK, Argonne Cancer Research Hospital, University of Chicago, Chicago, Ill.

"When news of the release of atomic energy broke dramatically upon the world with the explosion of the atomic bomb over Hiroshima, it was at once apparent that this new means of destruction presented problems of a medical nature not hitherto encountered." With this prelude the editors present this excellent volume, which now makes available in collated form the mass of medical data collected at Hiroshima and Nagasaki from studies done on the citizenry of those cities.

Another in the National Nuclear Energy Series (div. VIII, vol. 8), this volume is based on the six-volume report of the joint commission for the investigation of the effects of the atomic bomb in Japan. The editors, both members of the joint commission, representing the Medical Corps, General Headquarters, U. S. Army Forces Pacific and the Medical Corps, Naval Technical Mission to Japan, arrived in Hiroshima and Nagasaki within weeks after the holocausts to help direct and carry out the group studies here reported. That these data, which are basic to much of our understanding of radiation effects in man and are fundamental bases for the studies that continue in Japan, were ever collected or that the studies were ever carried out in the face of complete social and community disorganization is a tribute to the members of the joint commission and to the devotion of the Japanese physicians and scientists who did these things in the face of incredible difficulties.

Under the exigencies of the situation it was not possible for the Japanese to do detailed or controlled scientific studies on the injured populace. However, a very large amount of good work was done by them immediately. The joint commission teams arriving in the third or fourth weeks after the bombings cooperated in further studies.

Included in this volume are reports on the types of injuries produced, the numbers of casualties, clinical observations, hematological studies, pathological observations, and detailed analyses of the relationships between the lesions produced and distance from the explosion, shielding by buildings of varied composition, clothing, terrain, and so forth. The volume has been brought up to date by the inclusion of data recently collected by the U. S. National Research Council atomic bomb casualty commission's observations on the induction of neutron cataracts in the eyes and the increased incidence of leukemia in the survivors.

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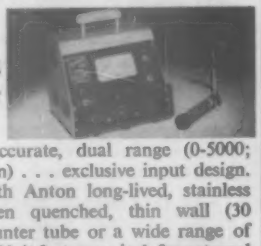

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cellent description of the pathological changes observed in those individuals succumbing to total body irradiation. These studies were carried out at the U. S. Armed Forces Institute of Pathology and will serve as a bench mark for future reference. As it was not possible to correlate the pathological and hematological findings with definitive dose levels of total body radiation, the authors and their colleagues have wisely analyzed these data in relationship to distance from the hypocenter and included, where possible, pertinent shielding factors. By this technique they have preserved these data in usable form for future analysis as other pertinent related data develop.

This report serves not only as a repository of scientific data but also as a social document of the first order. Here are recorded in exact and dispassionate prose the details of the instantaneous physical and social collapse of two cities under the impact of "nominal" fission bombs. At Hiroshima, "90 per cent of the 200 to 300 physicians were killed or injured, and at least 60 were killed outright. About 60 physicians were able to give medical care despite their injuries. Over 90 per cent of the 1800 nurses and orderlies were killed or injured." And further about Hiroshima—"Only 3 of the 45 civilian hospitals were usable." Describing the disruption at the two largest Hiroshima hospitals, both constructed of reinforced concrete and a mile from the hypocenter, the editors point out that the buildings were so badly damaged that they could not function as hospitals, but only as shelters and aid stations. In addition the casualty rate in each was ~ 90%.

In summary, this book records a wealth of important data that are basic to our understanding of the acute effects of the explosion of a "nominal" fission bomb on a large population and to the elucidation of the acute radiation syndrome in man. Its contents have been well known for a long time to those working in the field of radiation effects. It should now become required reading for all physicians and for all persons with that degree of social consciousness adequate to an understanding of its implications.

BOOKS RECEIVED

Basic Mechanisms in Radiobiology, IV. Cellular Aspects, edited by H. M. Pratt and E. L. Powers (National Academy of Sciences, Washington, D. C., 1956, ix + 190 pages, $1.75). Five papers that were presented at a 1955 symposium organized by the subcommittee on radiobiology of the National Academy, followed by the discussions they inspired, form the matter of this report. R. E. Zirkle discussed cellular changes; Cornelius Tobias, cell division; Carl Swanson, chromosome aberrations; S. Spiegelman, mutation production; Daniel Mazia, the relation of cell morphology to function—all as influenced by radiation.

Currents, Fields, and Particles, by Francis Bitter (Technology Press of Massachusetts Institute of Technology, Cambridge, Mass., and John Wiley and Sons, Inc., New York, and Chapman and Hall, London, 1956, xiv + 600 pages, $8.50). What nourishment does one offer to satisfy the appetite for physics of a college sophomore? This book is the second course menu at MIT and represents an "effort to base the second year of a two-year physics course on atomic physics." It is made up of treatments of electricity and magnetism, optics, wave mechanics, and atomic physics.

The rationale of a teaching program is difficult to examine in an age when teaching is the handmaiden of practicality. One does not know the basic purposes that the teacher has in mind. Here is an impressive array of phenomena to intrigue and capture the minds of future cyclotron operators. But one looks in vain for the rough and tough diet of vigorous, thoroughgoing analysis that might serve to develop the thinking powers of a curious student.

Circuit Theory and Design, by John L. Stewart (John Wiley and Sons, Inc., New York, and Chapman and Hall, London, 1956, xiv + 480 pages, $9.50). The author's subject is the application of pole-zero methods based on Heavisides operational calculus to the analysis and synthesis of steady-state circuit performance. After an introduction to circuits and function theory, the book proceeds to treat filters, amplifiers, oscillators, and servomechanisms.

Introduction to Solid State Physics, 2nd ed., by Charles Kittel (John Wiley and Sons, Inc., New York, and Chapman and Hall, London, 1956, xvii + 617 pages, $12.00). The three years since the publication of the first edition have made this book 200 pages longer. Perhaps this is commensurate with the

rate of development of the subject. The volume is intended as an introduction to the field, and it will be welcome to scientists and engineers who find semiconductors, ceramics, and ferromagnetism making themselves felt in places where they do not, classically, belong. The subject matter includes crystal properties, dia-, ferro-, antiferro-, and paramagnetism, metallic conduction, semiconductors, superconductivity, and photoconductivity.

Recent Advances in Science, Physics and Applied Mathematics, edited by M. H. Shamos and G. M. Murphy (Interscience Publishers and New York University Press, New York, 1956, xi + 384 pages, $7.50). Most of the papers that were presented at the symposium on nuclear science at New York University in the spring of 1954 are included in this volume. The material ranges from applied mathematics through atomic and nuclear physics, solid state physics, operations research, and on to the implications of modern science for industrial development. It is presented by outstanding authorities in each field in a manner that makes it understandable and useful to scientists and engineers in other branches of science.

Handbook of Industrial Electronic Control Circuits, by John Markus and Vin Zeluff (McGraw-Hill Book Co., New York, 1956, xiv + 352 pages, $8.75). Two editors of *Electronics* have gathered from their magazine significant circuits for control applications. The large-page format permits detailed diagrams. Sections include counting circuits, radiation circuits, and timing circuits of particular interest to nuclear people along with more general subjects touching on transistors, temperature control, etc.

Progress in Semiconductors, Vol. 1, edited by Alan F. Gibson (John Wiley and Sons, New York, 1956, vii + 220 pages, $8.00). This is the first annual volume of a set intended to keep the investigator up to date in semiconductor research. Chapters are devoted to silicon, germanium filaments, Seebeck effect, phosphors, high-frequency transistors, photo-magneto-electric effect, and field effects.

Handbuch der Physik, Vol. XXXVI, Atoms II, edited by S. Flügge (Springer-Verlag, Berlin, 1956, vi + 424 pages, $18.00). Here is the second volume on atoms of the venerable handbook. Two articles in German are on quantum mechanics of atoms (by Friederich Hund) and statistical treatment of the atom (by Paul Gombas). Two articles in English by H. S. W. Massey are concerned with atomic collisions and excitation and ionization.

Electricité, 6th ed., by G. Goudet (Masson and Cie, Paris, 1956, 4,500 fr, 5,100 fr; $13.00, $14.60). **Electricité,** by Y. Rocard (Masson and Cie, Paris, 1956, 3,000 fr, 3,500 fr; $8.60, $10.00). Here are two books to satisfy the needs of the serious student of physics or electrical engineering. The former is a part of the author's general physics course. It leans somewhat more toward theoretical aspects of the subject. The second has a somewhat more practical emphasis. The former treats relativity and quantum mechanics in more detail; the latter has discussions of klystrons and travelling-wave tubes.

Handbook of Chemistry and Physics (38th ed.), edited by C. D. Hodgman, R. C. Weast, and S. M. Selby (Chemical Rubber Publishing Co., Cleveland, 1956, xxii + 3206 pages, $12.00). The latest edition of this indispensable laboratory reference source contains the most recently accepted values of atomic constants and atomic weights. It includes revisions and extensions beyond element 93 in the tables of properties of isotopes and thermal neutron cross sections. There are also revisions associated with high-temperature work in addition to corrections in the data in some of the older sections.

Numerical Integration of Differential Equations, by A. A. Bennett, W. E. Milne, and H. Bateman (Dover Publications, Inc., New York, 1956, 108 pages, paperbound, $1.35). This book is a treatment of several new methods of numerically solving differential equations. The methods dealing with the integration of ordinary differential equations involve interpolation procedures by use of polynomials, successive approximations, and step-by-step methods of integration.

Rayleigh's Principle and Its Applications to Engineering, by G. Temple and W. G. Bickley (Dover Publications, Inc., New York, 1956, iv + 154 pages, paperbound, $1.50). This book on Rayleigh's principle, which relates the frequency of oscillation of an elastic system to the distribution of kinetic and potential energies in the system, is suitable for engineers and physicists. The energy method of analyzing dy-

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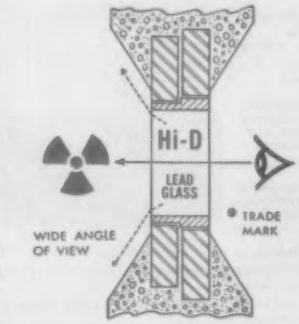

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namic systems is presented. Rayleigh's principle is then proved, not only for systems with a finite number of degrees of freedom but also for continuous systems.

Engineering Inspection, Measurement, and Testing, by H. C. Town and R. Colebourne (Philosophical Library, Inc., New York, 1956, 192 pages, $8.75). Modern machines and methods used for standardization and precision measurement are described for linear and angular measurements, straightness and flatness testing, and screw-thread and surface-finish measurement.

Photoconductivity Conference held at Atlantic City, November 4–6, 1954, edited by R. G. Breckenridge *et al.* (John Wiley and Sons, New York, 1956, xiii + 653 pages, $13.50). Another bring-up-to-date volume divides the field of photoconduction into 28 papers in 5 categories: phenomenological theory, photon absorption, electron processes, materials, current topics.

ALSO OF NOTE

Chart of the Nuclides. The fifth edition of the popular Chart of the Nuclides is available. It was prepared in the Knolls Atomic Power Laboratory for the AEC by John R. Stehn and Eugene F. Clancy. The new chart shows 1,388 nuclides, 112 more than the last edition, issued in 1953, comprising 101 elements. *Dept. 2-119, General Electric Co., Schenectady 5, N. Y., no charge.*

Physics in Medicine and Biology. This new journal of the Hospital Physicists' Association will be published quarterly with volume 1, No. 1, appearing in July 1956. Editor is J. E. Roberts, Middlesex Hospital, London. Emphasis will be on papers reporting research in studies of the physical properties and constitution of living matter at all levels of organization and applications of physics and the methods of physics to the elucidation of problems in medicine, biology, and physiology. *Academic Press, Inc., 111 Fifth Ave., New York 3, N. Y.; vol. 1, 4 issues (July 1956–April 1957), $9.80.*

Nuclear Metallurgy (Vol. 3). This is a report of a symposium on the effects of radiation on metals held by the Institute of Metals Div. of the American Institute of Mining, Metallurgical, and Petroleum Engineers in Cleveland, Oct. 8, 1956. The papers included are Theory and Mechanism of Radiation Effects in Metals by G. H. Vineyard, Irradiation Effects on Physical Metallurgical Processes by D. E. Thomas, and Irradiation Effects in Reactor Materials by D. E. Billington. *AIME, 29 W. 39th St., New York 18, N. Y., $3.75.*

Report of NRL Progress (monthly). Each issue contains articles and "problem notes" concerning Naval Research Laboratory nonclassified research and development. Reports can now be obtained on a subscription basis. *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C.; annual subscription—$10.00 domestic, $13.00 foreign; single issue—$1.25.*

A Review of the Air Force Materials Research and Development Program (PB 111648S). The review covers 205 reports from the Air Force's materials research and development program from July '54 to June '55. Research includes adhesives, metallurgy, packaging, etc. This publication supplements two earlier reviews of the same title. 137 p. *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C. $3.50.*

Government Research Reports on Rubber (CTR-321) and Adhesives (CTR-300). The catalog on rubber lists 193 reports and the one on adhesives 478. German technical papers captured by the Allies in World War 2 are also included. *Office of Technical Services, U. S. Dept. of Commerce, Washington 25, D. C., Rubber, $0.10; Adhesives, $0.25.*

Revised Tables to Correct for Physical Decay of Some Frequently Used Radioisotopes [ORO-26 (Rev.)]. These tables, by H. D. Bruner, give $e^{-\lambda t}$ for the time interval t. Time units were chosen to give a difference between succeeding entries of $e^{-\lambda t}$ of about 0.005. Half-life values were supplied by W. H. Sullivan, ORNL, from his revised "Trilinear Chart of Nuclides." 82 p. *Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C., $0.50.*

Accessory Equipment and Procedures for Use of a 1500 Curie Cobalt-60 Gamma Ray Source (PB 121378). This report is based on a Co^{60} source used at Wright Air Development Center to investigate gamma-radiation effects on materials. Accessories include a rotating-beam hoist, specialized container plugs, additional sample canisters, and a cooling system. 18 p.

Office of Technical Services, U. S. Department of Commerce, Washington 25, D. C., $0.50.

The Outlook for Nuclear Power in Japan. By M. Sapir and Sam J. Van Hyning for the NPA Committee on the Productive Uses of Nuclear Energy. This report, by M. Sapir and S. J. Van Hyning, analyzes future power requirements of Japan and the part nuclear power can play. 175 p. *National Planning Association, 1606 New Hampshire Ave., N. W., Washington 9, D. C., $3.00.*

LETTERS

Brazilian Activities

DEAR SIR:

Your story on Brazil's 18-point atomic policy (NU, Oct. '56, p. R5) is one of the most shocking commentaries that has ever been published in a paper as a criticism to the actions of the government of a friendly country . . .

There is one statement . . . that I must strongly reject: I am appointed as a "known communist" . . . I am known here and in many countries abroad (United States, Great Britain, France, Canada, India, Argentina, Mexico, etc.) as a man who has never shown any sympathy with either the communist ideas or party. Your statement will be as shocking to my friends in those countries as it was to me. I do hope that you do not agree with the idea of labeling as "known communists" responsible citizens of friendly countries whenever they suggest to their own government what they think is the best solution for some problems . . .

—Prof. M. D. de Sousa Santos
Director of the Instituto de Energia Atomica
São Paulo, Brazil

EDITOR'S NOTE: We regret very much that we published the statements about Prof. de Sousa Santos that appeared in the story referred to. We offer our apology to him.

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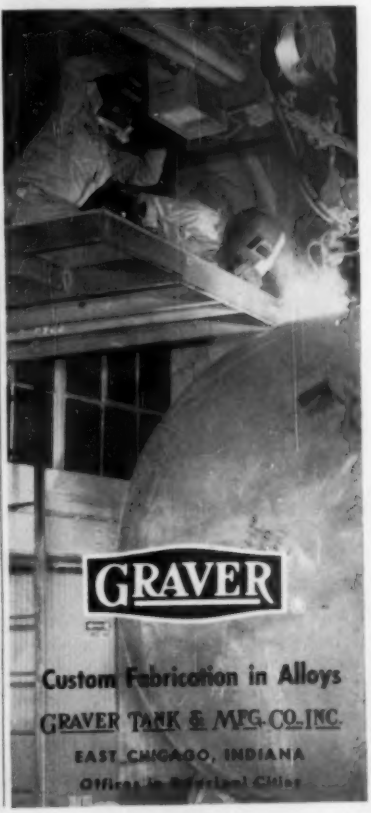

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Pocket *pH* Meter

Pocket-size meter (above), operated on flashlight batteries, has a *pH* range of 2–12. Instrument has a single electrode replacing usual reference and glass electrodes and a "memory" dial for use in standardising.—Scientific Instruments Division, Beckman Instruments, Inc., Fullerton, Cal.

Metal-Ceramic seals

AlSiMag seals are now made in production quantities. Can be supplied for silver solder brazing, hard or soft soldering.—American Lava Corp., Cherokee Blvd. & Mfgrs. Rd., Chattanooga 5, Tenn.

Dry Battery. Practically unlimited shelf life is claimed for new solid-electrolyte battery. Delivers low currents at 95 volts.—National Carbon Co, 30 E. 42nd St, N. Y. 17, N. Y.

Crystal Oven. JKO-12 weighs only 4.6 oz, operates over temperature range of −55 to +75° C with variation of $< \pm 1°$ C.—James Knights Co, Sandwich, Ill.

Dry-box gloves. Long gauntlet neoprene gloves come in 27-in. length with 5-in. i.d. opening at top of sleeve; also available in 30-, 32- and 36-in. lengths with 8-in. opening.—Surety Rubber Co., Carrollton, O.

Ultrasonic waste disposal. Ultrasonic energy generated by Multiwhistle RB Air-Jet unit will soon be available for experimental studies on radioactive waste disposal.—Gulton Industries, Inc., 212 Durham Ave., Metuchen, N. J.

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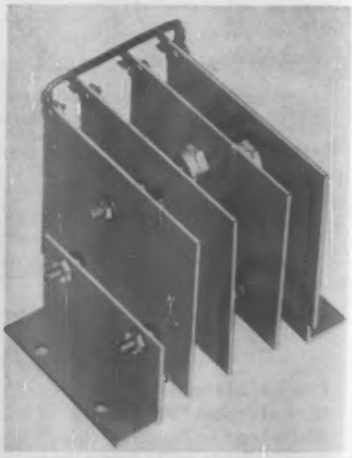

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REACTOR SHIELDING DESIGN MANUAL

488 pages, 7⅞ x 10¼, 269 illustrations, $6.00

This is an engineering treatment, showing how to design practical reactor shields, largely based on methods and data used for naval reactors and the Pressurized Water Reactor, which is the first large reactor for utility power generation.

In general the information is presented in the order a designer would have to accumulate it in developing a shield design. The book deals with such subjects as basic processes, determining allowable radiation levels, shielding the reactor core and the cooling system, shield engineering, the effect of irregularities in shield, and the effect of geometry of radiation source. The influence of plant layout, structure, and maintenance upon design is taken into account. The volume is fully indexed.

The methods discussed form a basic rather than a mock-up approach and thus permit design of shields without expensive and time-consuming use of the reactor facilities in which full-scale shielding mock-ups can be made. This manual should simplify and lessen the time required for design of power reactor shields.

Also sponsored by the Naval Reactors Branch Atomic Energy Commission:

METALLURGY OF ZIRCONIUM

50 specialists report on present state of zirconium technology, covering occurrence, reduction, refining, properties, fabrication, and uses. Editors: B. Lustman, Westinghouse, and F. Kerze, Jr., Reactor Devel. Div., AEC. 776 pp., 6 x 9, 312 illus., $10.00

The following 6 volumes have been prepared by the U. S. ATOMIC ENERGY COMMISSION

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REACTOR HANDBOOK: PHYSICS

Covers reactor physics and radiation shielding. Discusses theoretical and experimental techniques used in designing and evaluating various experimental and research reactors. Experimental and calculated solutions for various shielding problems are catalogued and methods of tailoring these solutions to new problems are developed. 790 pp., 7¼ x 10¼, illus., $12.00.

REACTOR HANDBOOK: ENGINEERING

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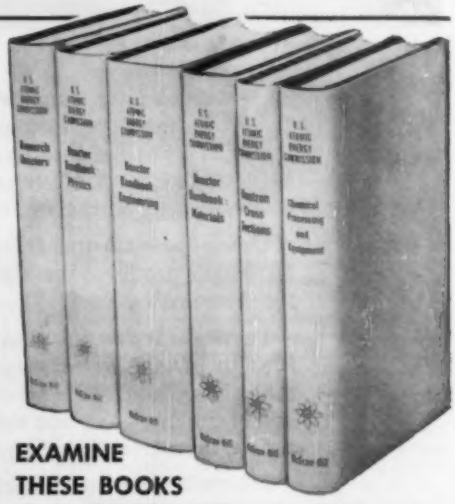

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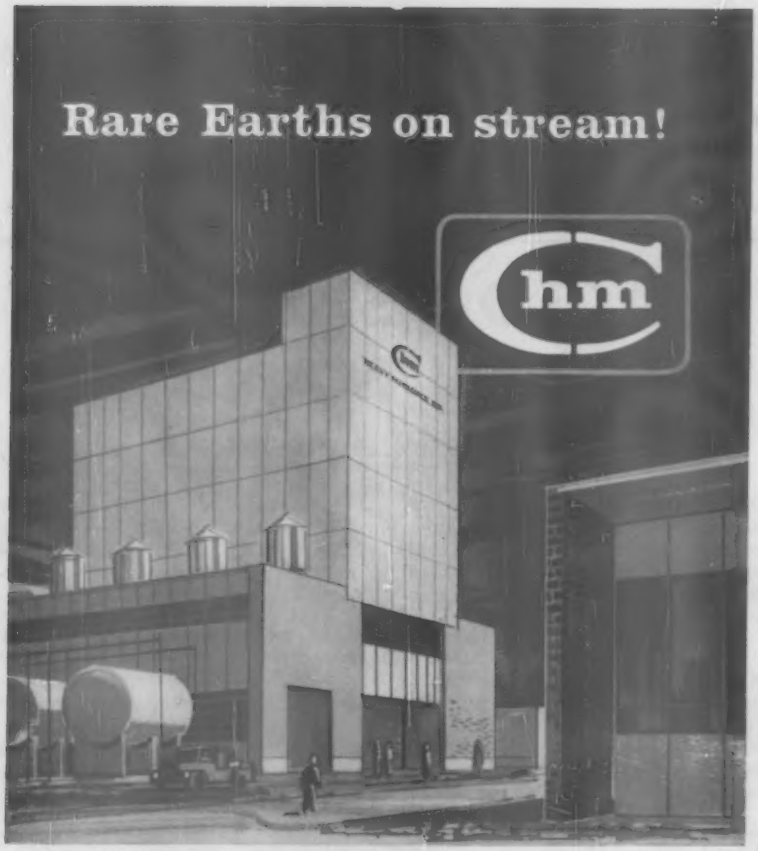

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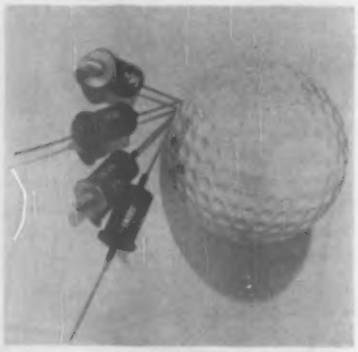

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NEWSMAKERS

Oak Ridge Operations Office of AEC has named **W. R. McCauley, Jr.**, to be Deputy Assistant Manager for Administration. Active in the national atomic energy program since 1943, he had been Assistant to the Manager since 1951.

Westinghouse Commercial Atomic Power Activities has promoted three: **W. D. Shepherd** from sales manager to assistant to manager **Carroll V. Roseberry; W. L. Budge** sales manager to succeed Shepherd; **O. C. Kebernick** from administrative assistant to the manager to a new post as assistant sales manager.

Admiral William M. Fechteler, former Chief of Naval Operations, joins General Electric as a planning consultant in the firm's Atomic Products Division. He will be located in Washington and will do long-range planning work in the field. GE also announced appointment of three mathematicians to its Submarine Advanced Reactor project: **Robert C. Luippold** from New York State College for Teachers at Albany; **Robert D. Burgess** from Michigan U.; and **John H. Hoelzer** from Columbia U.'s division of war research.

Convair has engaged for its nuclear program **N. H. Godbold** from AEC's Idaho Operations Office; **P. N. Stevens,** a recent ORSORT graduate; **R. D. Sheffield** and **R. A. Miller** from Mississippi U.'s math department. The first two are working on reactor design, the last two on nuclear analysis. Another General Dynamics division, General Atomic, has named to the staff of its Hopkins Laboratory in San Diego **Theodore B. Taylor,** a theoretical physicist from Los Alamos; **Harold A. Thomas,** physicist from the National Bureau of Standards, and **Lloyd Zumwalt,** physical chemist from Nuclear Science and Engineering Corp.

Nuclear-Chicago Corp. has elected **James M. Phelan** to be president and board chairman. He has been a member of the board since 1952.

James G. LeSieur, Jr., chief of the government personnel branch at Oak Ridge for 13 years, moves to AEC's Grand Junction, Colo., Operations Office as director of the organization and personnel division.

Sandia Corp. has promoted **W. J. Howard** from head of one of two engineering departments at Livermore to director of systems development there

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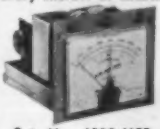

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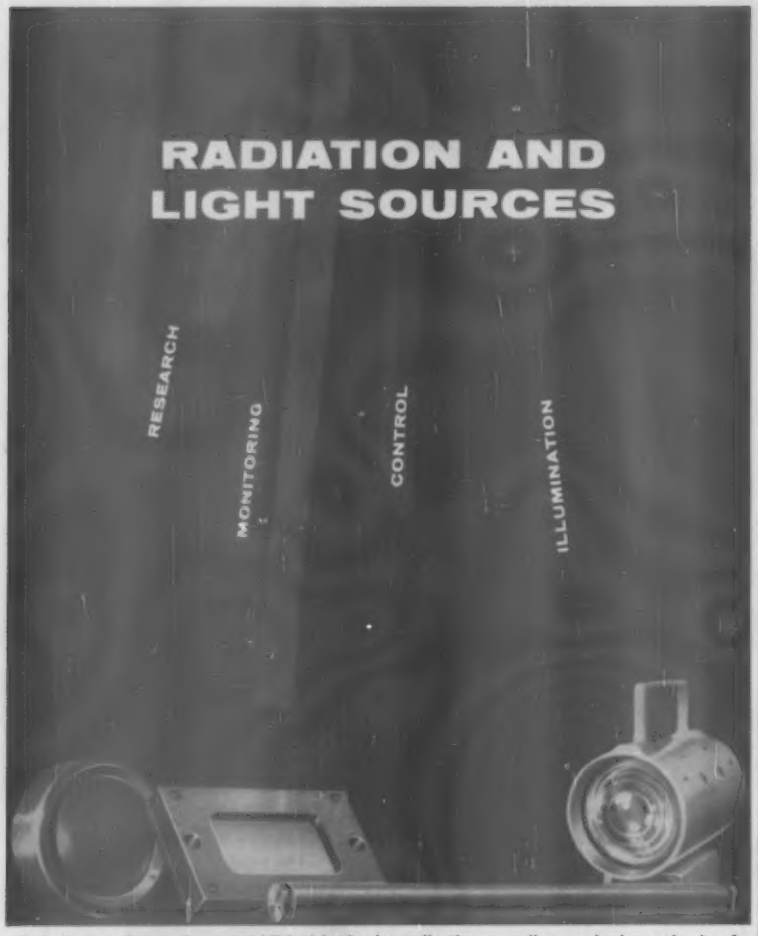
Cleveland Electronics Show, Feb. 16–17, Masonic Auditorium



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—in effect, head of its Livermore facility. He has been with Sandia since 1946. The firm will build a $5-million permanent facility for its Livermore branch, now housed in the University of California Radiation Laboratory.

Yankee Atomic Electric Co. has added mechanical engineer **Henry C. Mikszto-wicz** to its technical staff.

John R. Hendrickson, Sr., physical scientist in radiological research and development at the Army Chemical Center in Maryland, has joined the standards engineering department of Defense Electronic Products, an RCA subsidiary in Camden, N. J., as consultant on radiation effects. He had served with the Manhattan District and AEC from 1942 to 1949.

Isidor I. Rabi, Higgins Professor of Physics at Columbia U. and chairman of AEC's General Advisory Committee, is serving as a visiting professor at MIT during the fall term.

National Research Corp. has appointed **Philip J. Clough** director of its metallurgical research department.

Max C. Farmer, staff metallurgist for the National Academy of Sciences in Washington, has been named to the newly-created post of technical director in the Beryllium Corp., Reading, Pa.

After two years of research at the Nobel Institute and the Swedish Academy of Science in Stockholm, Israeli nuclear scientist **Marcel Schmorak** has returned to his country to join the nuclear physics staff of the Weisman Institute at Rehovot near Tel-Aviv.

Battelle Memorial Institute has named **Eugene Simons** consultant in its engineering mechanics division. Having had wide experience in Battelle's nuclear energy program, he will take responsibility for the effectiveness of the Institute's research on nuclear propulsion of aircraft.

Sidney Siegel, technical director of Atomics International (NAA), was elected president of the newly-formed Los Angeles section of the American Nuclear Society. AI has also appointed **R. A. Edman** superintendent of manufacturing, succeeding **D. N. Petersen. R. H. J. Gercke** has been named supervisor of the physical and chemical properties unit in the organic reactor group, and **M. Silberbert** responsible engineer for heat transfer surface studies on the OMRE project. **R. H. Sehnert** becomes eastern representative for AI, with offices in Washington.

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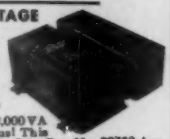

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NUCLEAR CALENDAR

March 11–15—1957 Nuclear Congress, will include four events, all at Convention Hall, Philadelphia: **A.** Second Nuclear Engineering & Science Congress (EJC), running all 5 days; contact T. A. Marshall Jr., ASME, 29 W 39, NYC 18. **B.** Fifth Atomic Energy for Industry conference (NICB), **14–15th**; contact E. A. Hammersfahr, NICB, 460 Park Ave., NYC. **C.** International Atomic Exposition, all 5 days; contact J. V. Friel, 304 Architects Bldg., Philadelphia 3. **D.** Fifth Hot Labs & Equipment Conference (Hot Laboratories Committee), **14–15th**; contact Frank Ring Jr., ORNL, Oak Ridge, Tenn.

March 18–27—National convention IRE, New York; professional group on nuclear science meets **20th** (*Waldorf*); exhibits (*Coliseum*). Contact IRE, 1 E. 79 St., NYC.

March 27–29—Colloquium on radiation effects on materials. (Office of Naval Research, and Glenn L. Martin Co.), Baltimore (*Johns Hopkins Univ.*). Contact Jerome Morse, Martin, Baltimore 3, Md.

April 16–18—Symposium on nondestructive tests in the nuclear energy field (Am. Soc. for Testing Materials jointly with ANS, AIChE and the Society for Non-Destructive Testing), Chicago (*Morrison*). Contact W. J. McGonnagle, Argonne National Laboratory, Lemont, Ill.

April 29–May 1—Eighth annual spectroscopy symposium (Am. Asen. of Spectrographers), Chicago (*LaSalle*). Contact T. H. Zink, 4528 Division St., Chicago 51.

May 14–16—Second annual Industrial Nuclear Technology conference on applied uses of radiation (Armour Research Foundation and NUCLEONICS), Chicago (Museum of Science and Industry). L. Reiffel, ARF, 3440 S. State St., Chicago.

May 28–29—Second reactive metals conference (So. California section AIME), Los Angeles (*Ambassador*). Contact B. S. Mesick, Arthur D. Little Inc., Los Angeles.

June 6–8—Third conference on nuclear structure (Univ. Pittsburgh), Pittsburgh. Contact Norman Austern, Sarah M. Scaife Radiation Laboratory, Univ. Pittsburgh.

June 24–26—Third annual meeting, American Nuclear Society, Pittsburgh (*Wm. Penn-Sheraton*). Contact W. W. Grigorieff, exec. secy., Box 963, Oak Ridge, Tenn.

Oct. 27–Nov. 1—Fourth annual meeting, Atomic Industrial Forum and third annual Trade Fair of Atomic Industry concurrently with fall meeting of American Nuclear Society, New York (*Coliseum*). Contact D. J. Scherer, AIF, 3 E. 54, NYC 22.

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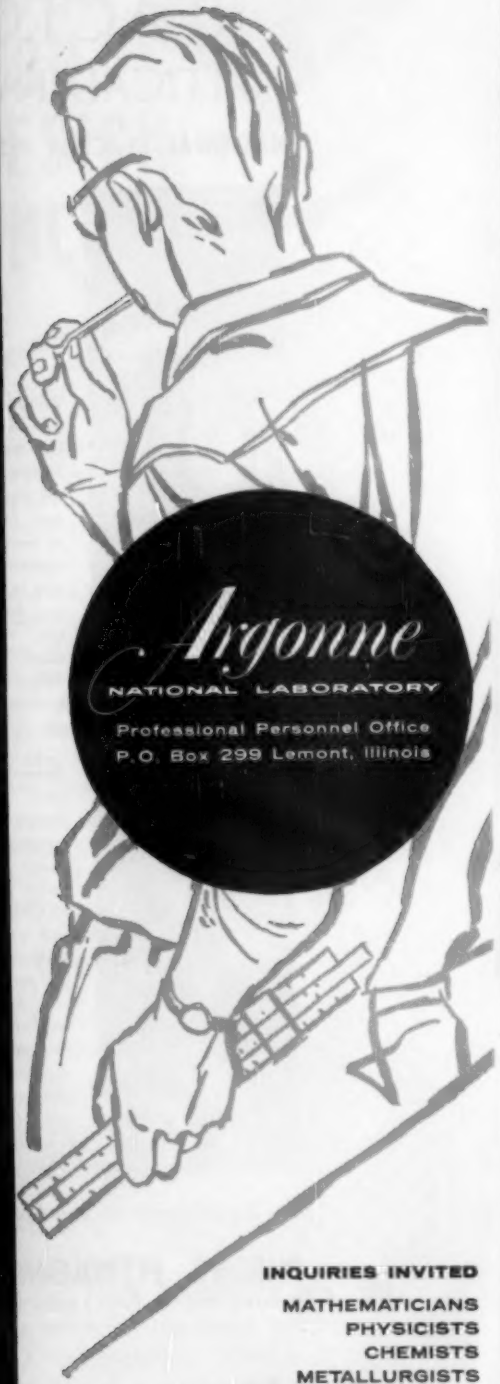

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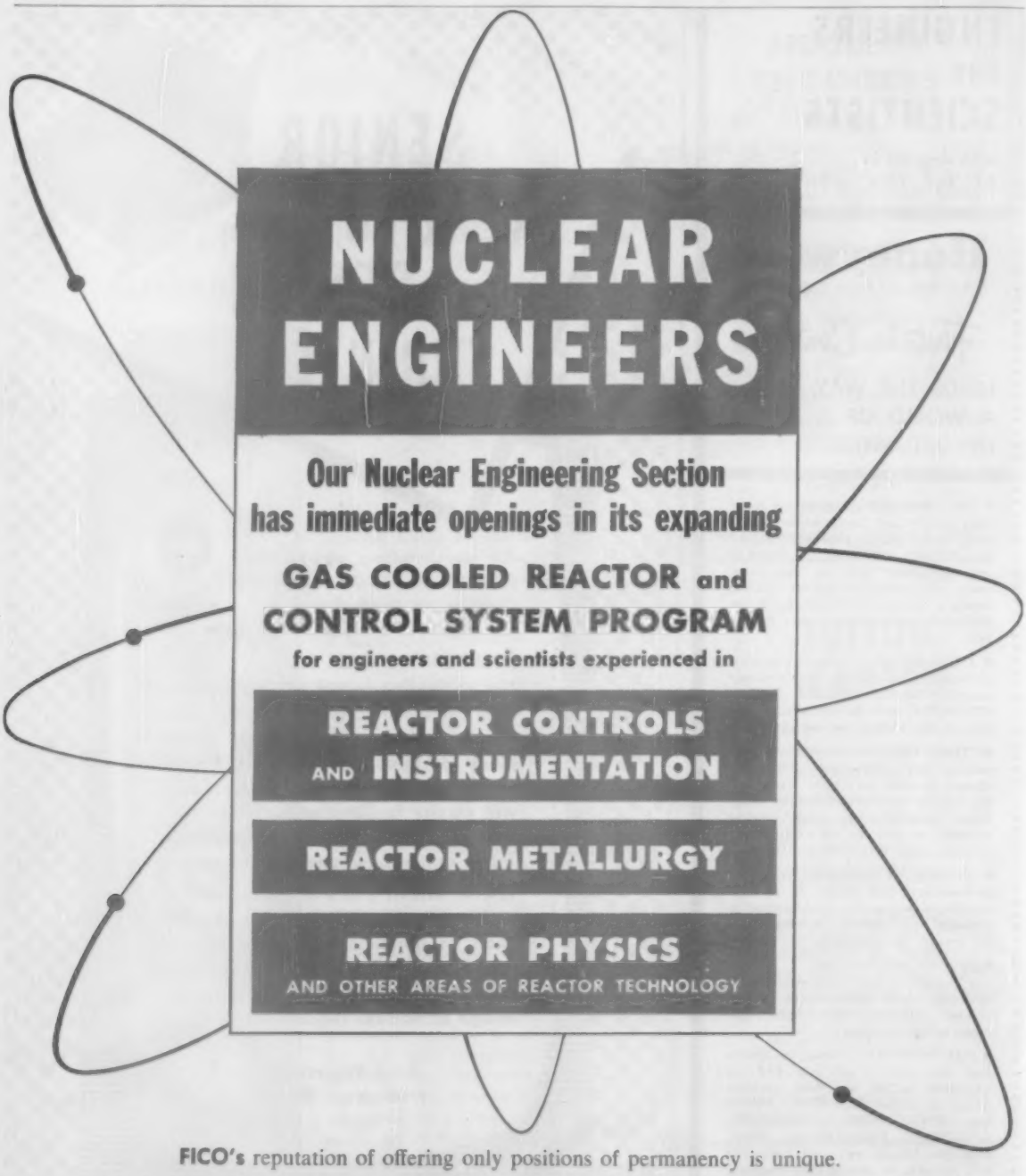

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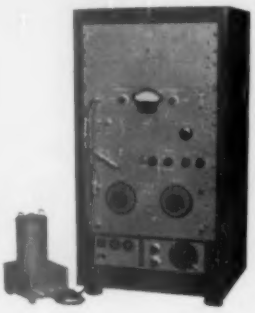

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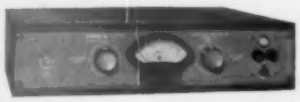

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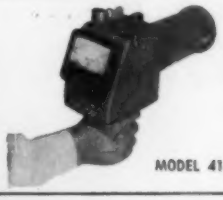

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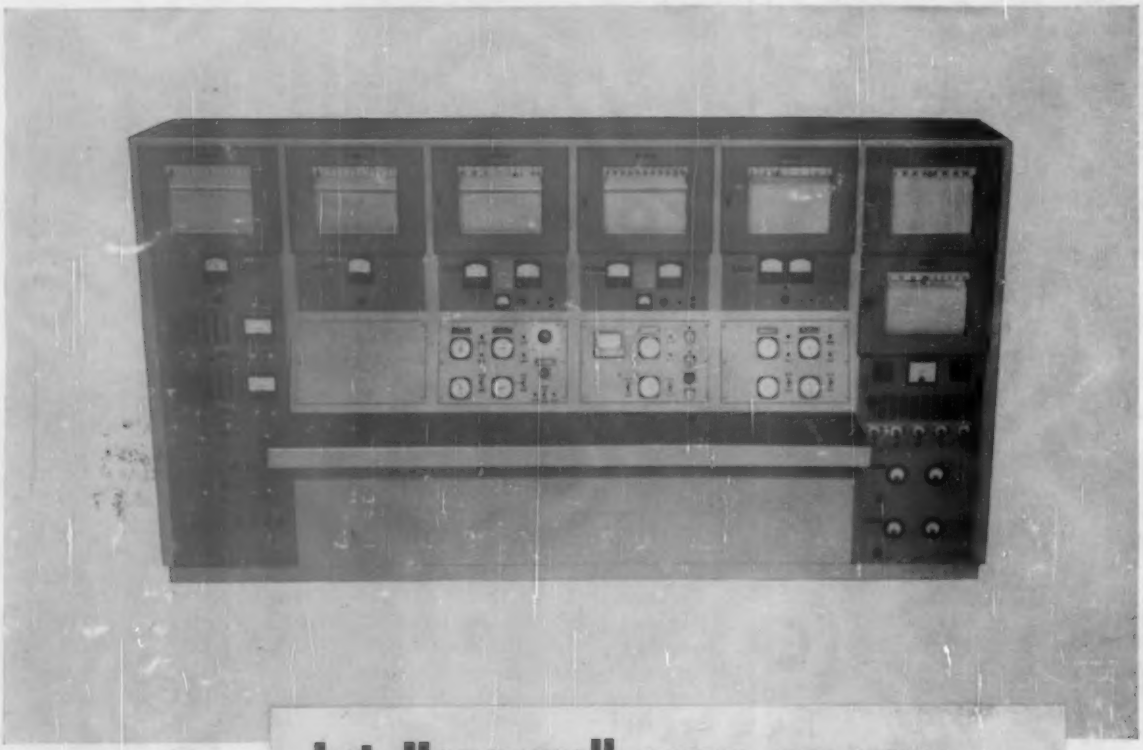

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